ANALYSIS OF BUILDING INFORMATION MODELING (BIM) PERFORMANCE USING BIG DATA FROM A CONSTRUCTION PROJECT

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ABSTRACT

ANALYSIS OF BUILDING INFORMATION MODELING (BIM) PERFORMANCE USING BIG DATA FROM A CONSTRUCTION PROJECT

This study aims to propose a systematical approach for evaluating BIM performance from a main contractor's perspective based on big data from a construction project. Retrospective case study is used as the research approach. Data is collected through interviews with the main contractor firm, and data from the logged project information in project databases including ACONEX and Microsoft Excel files. A framework containing performance metrics, specifically tailored to evaluate BIM performance based on big data, is developed from the combined analysis of literature review, interviews with main contractor, and overview of the project data. Collected project data and interview data are analyzed using the developed framework. Results of the data analysis are verified through follow-up interviews with the main contractor firm.

Findings of the study suggest that it is possible to evaluate the BIM performance through analysis of collected BIM big data using the proposed systematical approach. Several performance problems were identified during the data analysis. Follow-up interviews revealed that identified performance problems from the data analysis largely coincided with the real-life experiences and accurate data entry is the key criterion for the analysis to yield correct results. The proposed framework should be tested in wider range of studies and may serve as a foundation for a future benchmarking system. Future work should focus on refining performance metrics, establishing a BIM big data database for benchmarking, exploring data's potential to be used for real-time performance assessment, and implementation of emerging Artificial Intelligence (AI) techniques for the analysis of big data.

Keywords: *BIM; BIM Performance; Big Data; Construction Project Performance*

ÖZET

BİR İNŞAAT PROJESİNE AİT BÜYÜK VERİNİN KULLANIMI İLE YAPI BİLGİ MODELLEMESİ (YBM) PERFORMANSININ ANALİZİ

Bu çalışma, bir inşaat projesine ait büyük veriye dayanarak YBM performansını ana yüklenicinin bakış açısından değerlendirmek için sistematik bir yaklaşım önermeyi amaçlamaktadır. Araştırma yaklaşımı olarak retrospektif vaka çalışması seçilmiştir. Kullanılan veri, ana yüklenici firma ile yapılan röportajlar yoluyla ve proje boyunca ana yüklenici tarafından ACONEX ve Microsoft Excel veri setleri gibi çeşitli yollarla proje veri tabanlarına kaydedilen proje bilgilerinin elde edilmesi yoluyla toplanmıştır. Literatür taraması, ana yüklenici ile görüşmeler ve verilerin ön incelemesi sonucu, büyük veriye dayanarak BIM performansını değerlendirmek için özel olarak uyarlanmış performans metriklerinden oluşan bir değerlendirme çerçevesi geliştirilmiştir. Toplanan ham proje verileri ve görüşme verileri, geliştirilen çerçeve kullanılarak analiz edilmiştir. Veri analizi sonuçları, ana yüklenici firma ile yapılan ek röportajlar yoluyla doğrulanmıştır.

Bulgular, toplanan BIM büyük verisinin, önerilen sistematik yaklaşım kullanılarak analizi yoluyla BIM performansının değerlendirmenin mümkün olduğunu göstermektedir. Veri analizi sırasında çeşitli performans sorunları tespit edilmiştir. Ana firma ile yapılan görüşmeler, tespit edilen performans sorunlarının büyük ölçüde gerçek yaşam deneyimleri ile örtüştüğünü göstermiş ve aynı zamanda verilerin doğru ve gerçek durumu yansıtır şekilde girilmesinin analizlerin doğru sonuç vermesi için temel kriter olduğunu ortaya koymuştur. Önerilen yaklaşım, daha geniş bir vaka yelpazesinde test edilmelidir ve aynı zamanda gelecekte oluşturulacak bir kıyaslama sisteminin temelini oluşturabilir. Gelecekteki çalışmalar, performans metriklerini iyileştirmeye, kıyaslama için bir BIM büyük verisi veri tabanı oluşturmaya, verilerin gerçek zamanlı performans değerlendirmesi için kullanılması potansiyelini keşfetmeye ve büyük verilerin analizi için, günümüzde giderek gelişen ve uygulaması yaygınlaşan Yapay Zeka (AI) tekniklerinin uygulanmasına odaklanmalıdır.

Anahtar Kelimeler: *YBM; YBM Performansı; Büyük Veri; İnşaat Projesi Performansı*

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LIST OF ABBREVIATIONS

BIM: Building Information Modeling

BSC: Balanced Score Card

KPI: Key Performance Indicator

CSF: Critical Success Factor

MC: Main Contractor

BM: BIM Manager

BEP: Building Execution Plan

CHAPTER 1

INTRODUCTION

BIM performance is an important topic for construction industry that has gained significant attention lately since BIM adoption rate is rising. At the same time, big data concept and big data analytics gained importance since the datasets became too large and complex with increasing variety of data sources. Analysis of this big data have a potential to reveal valuable insight about the performance. This study seeks to investigate the ways of using construction big data to evaluate the BIM performance. To understand the topic of BIM performance measurement and how big data can be used for BIM performance measurement, one must first understand the importance of performance measurement topic in general, as well as importance and application of performance measurement in construction industry. Therefore, in the beginning, the topic of performance measurement and its importance is introduced shortly. Following that, importance and application of performance measurement in construction industry and underlying expectations of BIM implementation with its expected impact on construction performance are briefly discussed. After that, topic of BIM performance and existing studies on BIM performance measurement are introduced shortly. Finally, the relationship between BIM performance measurement and big data is introduced with focus on existing literature and gaps in these studies.

Performance measurement is an important topic that has gained significantly more attention since the 1990s. Bassioni et.al. (2004) stated that performance measurement emerged as a significant factor for achieving success due to globalization and business environment evolving into a more competitive one. Meanwhile, organizations have been adopting new tools and processes to measure performance. Niven (2002) stated that performance measurement methods like balanced scorecard is commonly adopted across various industries and organization types. Construction industry is one of these industries in which performance measurement is a topic that has been studied for a long time, and the notion is becoming increasingly popular.

After reports that are showing the performance problems in construction industry and stating the need for performance measurement (Latham, 1994; Egan, 1998), and research criticizing the underperformance within the construction industry (Love and

Gunasekaran, 1997; Kagioglou, 2001; Vrijhoef and Koskela, 2000), development and investigation of performance measurement methods and tools to assess and improve performance in construction industry has dramatically increased. These tools and methods have been used to measure performance on three different levels: (1) project level, (2) organizational level, and (3) stakeholder level (Yang, 2010). During the development of performance measurement tools and methods, various frameworks and systems were used, including but not limited to balanced scorecard system (Kagioglou, 2001; Yu et.al., 2007; Ali et.al., 2016), benchmarking models (CII, 2001; Ramirez et.al., 2004), and artificial neural network models (Alaloul et.al., 2018; Maya et.al., 2021). Proposed performance measurement methods mainly focus on measuring the performance based on identified performance metrics and key performance indicators (KPIs). Time, quality, cost, client satisfaction, productivity, and technology and innovation are the most common metrics and KPIs.

Despite the increased efforts of improving the performance in construction industry during the beginning of 2000s, several studies showed that construction performance continued to perform poorly, showing stagnant or even reduced performance, specifically in terms of productivity (Teicholz, 2004; National Institute of Building Science, 2007; Changali et.al., 2015). Changali et.al. (2015) stated that this poor productivity performance combined with poor organization and lack of effective communication resulted in cost overruns, especially in larger scale projects. Teicholz (2004) and Changali et.al. (2015) also stated that additional technological and innovational approaches are needed to improve productivity, therefore performance in the construction industry. Figure 1.1 indicates that working productivity in manufacturing industry significantly improved over the years, however worker productivity in the construction industry almost remained the same. The improvement in the manufacturing industry is assigned to adoption of innovative and modern technology for processes. This situation has led to BIM being proposed as a solution to performance problems, therefore resulted in an increase in its implementation rate.

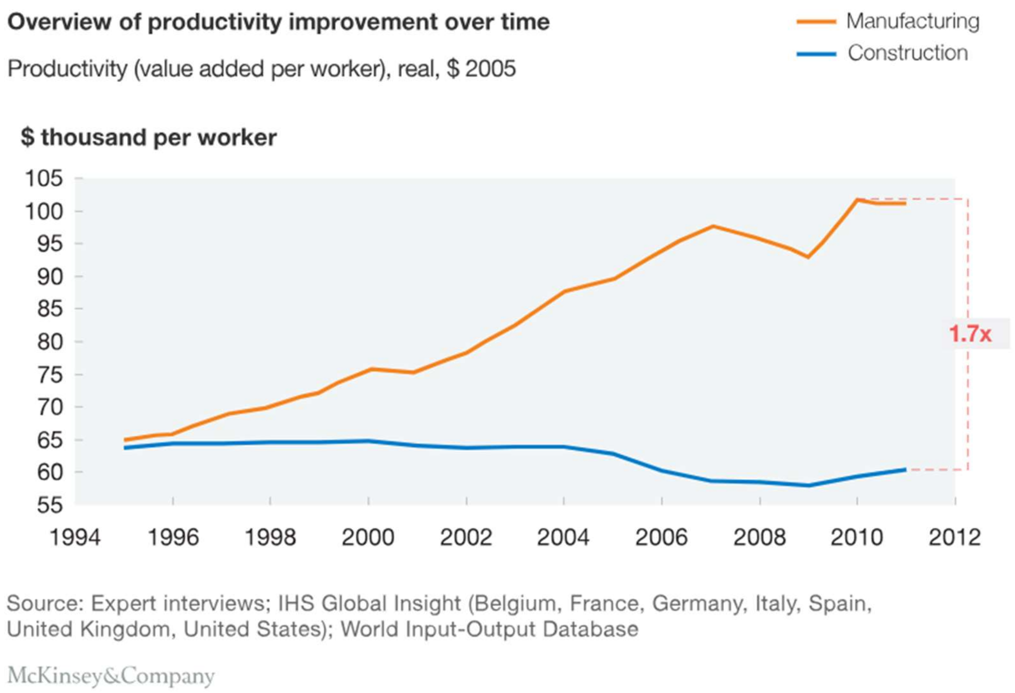


Figure 1.1. Productivity in construction industry has not improved over the years when compared to the productivity in manufacturing industry. (Source: Changali et.al., 2015)

Building information modeling (BIM) can be considered as a technological and innovational approach that is introduced to solve encountered problems (Elmualim and Gilder, 2014) and to improve the efficiency and productivity in construction industry (Azhar, 2011). According to National Institute of Building Sciences (NIBS, 2007), BIM can be defined as “a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward”. Benefits of BIM implementation in construction projects has been identified by previous research. Chan et.al. (2019) carried out an extensive literature review and summarized benefits of BIM implementation as follows: (1) improved project quality, (2) better understanding of design, (3) providing life cycle data, (4) scope clarification, (5) faster design process, (6) reduced construction cost, (7) better construction cost estimate and control, (8) better construction planning and monitoring, (9) more efficient communication, (10) reduced project duration, (11) improved safety performance, and (12) enhanced organizational image. These identified benefits have a positive impact on identified construction project performance metrics and KPIs, therefore it is safe to assume that BIM implementation to have a possible positive impact on the project performance. Abdirad (2016) pointed out to the relationship between BIM and project performance and stated that main objectives and goals of the BIM, which are defined as enhanced productivity, decreasing construction waste, and improved functionality throughout the different stages of the project's life cycle, are in line with the required improvements by the industry. Such alignment indicates that the construction performance would be closely related with BIM performance in the BIM based construction projects. Therefore, the related research area also covered the investigation of BIM performance measurement to evaluate the BIM implementation alongside with its effects on construction performance. Eastman et.al. (2011) stated that BIM is a complex process including collaboration, communication, and workflows, and BIM progress should be evaluated based on identified metrics when adopting BIM. To address the need of performance measurement methods, various studies are conducted. Several approaches are present in the literature regarding the BIM performance measurement, including measuring the BIM performance based on organizational maturity (Succar,2012), benchmarking BIM performance against other projects and leading companies (Du et.al., 2014; Choi et.al., 2018), comparison between BIM and non-BIM projects (Barlish and Sullivan, 2012), KPIs (Poirier et.al. 2015; Khanzadi et.al., 2020), assessment areas and dimensions (Nepal et.al., 2014; Kam et.al.,2017). Previous studies also investigated the effects of BIM Execution Plan (BEP) together with BIM implementation while measuring the BIM performance (Franz et.al., 2019; Yılmaz et.al., 2019).

1.1. Research Problem and the Aim of the Study

Abdirad (2016) pointed out to the presence of large number of unique performance metrics that indicates the complexity involved in BIM performance measurement and stated that performance metrics and KPIs should be specifically tailored to each BIM practice while evaluating BIM performance. This complexity increases with the introduction of "BIM big data" to BIM performance evaluation. Big data, as defined by Oracle, is the "data that contains greater variety, arriving in increasing volumes and with more velocity". Construction companies are showing an increasing interest to log every work they had done during a project. Logging project data can be done by means of using programs like Oracle ACONEX that do such data logging automatically, or companies may direct employees to manually log their work. Main reasons of the increasing interest on logging are monitoring and evaluating the performance. This logging of project data result in a "BIM big data", which is a combination of project data consisting of different types of information from different sources. For example, BIM data that is used in this thesis is composed of 48 excel files, exported from multiple sources, containing 746184 rows of data, with each row containing 11 to 12 columns of information. This big data differs from the data that was used in studies about BIM performance measurement from the literature. The data had to be specifically filtered and categorized so that it could be used for the performance evaluation. There are studies related to BIM and big data within the literature (Bilal, Munir et.al., 2016; Bilal, Pasha et.al., 2016; Chen et.al., 2016; Huang, 2021), but investigating these studies reveals that while there are studies focusing on some aspects of performance like cost management (Lu, 2018; Huang, 2021), there is little to no effort had been made to provide a complete performance measurement approach. Therefore, additional studies focusing on ways of organizing (categorizing and filtering) such "BIM big data" and offering "BIM big data" based BIM performance evaluation approaches is needed.

The purpose of this study is to propose a systematical approach for evaluating BIM performance from a main contractor's perspective based on big data from a construction project. The main research question is: *How can we evaluate the BIM performance using big data from construction?* This research question can be split up into two sub-questions considering the logical path followed throughout the thesis. Before beginning the performance analysis, one must identify performance measurement metrics and areas to be used. Therefore, first sub-question is: *What are the performance metrics required for evaluating the BIM performance based on big data from construction?* Identification of the performance metrics alone is not sufficient for BIM performance analysis on this type of construction big data. Therefore, alongside with the identification of performance metrics, proper data parameters that allow researcher to analyze performance based on identified metrics should be identified. Thus, second sub-question emerges as: *What are the needed data parameters for the analysis of BIM performance based on big data from a construction project?* After the parameters and performance metrics are identified, big data can be filtered and analyzed according to these metrics and parameters.

1.2. Methodology of the Study

In this study, case study method is used as research methodology. Case project presented in this study is a construction project in Dubai and can be categorized as a retrospective case. Data is gathered from interviews with the main contractor firm, alongside with the project BIM Execution Plan (BEP) documents and project big data including employee worklogs, ACONEX logs and human resources sheets. Two types of interviews were conducted during the study; (1) general interviews, which are conducted to acquire a general understanding of the project and to identify potential criteria and areas for performance analysis, and (2) follow-up interviews, which are conducted to validate the data analysis results and understand the underlying reasons for performance problems. These interviews are recorded for future analysis during the study. Project big data used in this project is from the construction stage of the project and mainly belongs to the BIM department of the main contractor firm. Main contractor firm joined the project in construction phase, after the design phase of the project which was carried out by two different design firms. Main contractor firm was responsible from all production and delivery processes in the construction phase alongside with the subcontractor firms. Although the main contractor firm was involved in the project in construction phase of the project, they had to participate in a process in which design and construction phases had to be carried out together due to the design problems and constant design changes in the project.

Based on the analysis of general interviews with the main contractor firm, extensive literature review and overview of the acquired project big data, a framework including identified performance metrics and required parameters for data analysis was developed. Developed framework was used for analyzing BIM performance based on gathered project data. Data analysis results were verified with follow-up interviews. Results showed that developed framework was sufficient to identify performance problems in the project if the data used for analysis were correctly entered and reflects the real-life situation.

1.3. Limitations of the Study

Due to the difficulty of accessing and collecting construction big data from construction companies, the study could only be tested on the single available case data.

Although it is possible to consider of the tested case as two separate projects, A04 and A2A3, due to the size and characteristics of the case, the proposed approach needs to be tested on a larger number of cases, preferably from different companies. In addition, the interviews conducted for the performance analysis and determination of the performance problems were made only with the main contractor company, since the subcontractor companies could not be reached. Interviews with subcontractors would have helped to gain a more comprehensive view of the problems and their causes.

1.4. Outline of Thesis

This thesis consists of five chapters. Chapter 2 provides background information from the literature, about the construction performance and measurement methods, BIM performance and measurement methods, and how big data is used together with BIM. Chapter 3 describes the research methodology that is used in thesis and introduces the developed framework for performance evaluation. Data collection methods, research steps, and identified metrics are also explained in this chapter. Chapter 4 begins with the introduction of the case project and explanation of BIM usage in the case project. Later BIM performance of the case project is analyzed using raw project data, interview data, and the analysis of the projects' BEPs according to the identified metrics in the developed framework. Chapter 4 concludes with the discussion of the analyses results. Thesis concludes in Chapter 5 with a summary of the thesis, together with the limitations of the study, and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

In this chapter, an extensive literature review about the construction performance and BIM performance is carried out to identify performance measurement metrics and criteria for construction performance (Section 2.1.) and BIM performance (Section 2.2.). After that, literature review about big data and BIM (Section 2.3.) is presented.

2.1. Construction Performance

In this section, the relevant literature about construction performance and measurement methods is presented. Studies mainly explored the construction performance based on two main measurement metric types: (1) critical success factors (CSFs) and (2) key performance indicators (KPIs). Critical success factors (CSFs) can be defined as “those characteristics, conditions or variables that, when properly sustained, maintained, or managed, can have a significant impact on the success of a firm competing in particular industry” (Bruno and Leidecker, 1984). Looking from a project perspective, CSFs can be defined as “factors which, if addressed, significantly improve project implementation chances” (Pinto and Slevin, 1987). Key performance indicator (KPI) can be defined as “compilations of data measures used to assess the performance of a construction operation” and used for comparing “the actual and estimated performance in terms of effectiveness, efficiency, and quality in terms of both workmanship and product” (Cox et.al, 2003). These measures can be both quantitative and qualitative (Sibiya et.al., 2015).

Latham (1994) and Egan’s (1998) reports about the construction industry, where they mentioned the need for performance measurement to realize performance improvements and areas for improvement, accelerated the development process of key performance indicators (KPIs) for construction industry (Ahmad et.al, 2016). Capital cost, construction time, predictability, defects, accidents, productivity, and turnover and profits are seven identified areas with potential for improvement according to the Egan’s (1998) report.

In 2002, as a direct consequence of the Egan's (1998) report, Construction Best Practice Program's (CBPP) introduced "CBPP-KPI" including the KPIs for performance measurement, based on the seven identified areas for performance improvements on Egan's report (Bassioni et.al., 2004). CBPP-KPI includes ten key performance indicators grouped under two main categories: project performance, and company performance. Cost predictability, time predictability, construction cost, construction time, defects, client satisfaction-product and client satisfaction-service are the identified KPIs related with **project performance**, while safety, profitability and productivity were the KPIs related with **company performance**. According to Kagioglou et.al. (2001), metrics on the CBPP-KPI are clearly tailored to project level performance and provided minimal insights into the business performance of the companies despite having metrics regarded under company performance category. To address this gap, Kagioglou et.al. (2001) offered a conceptual framework expanding on the principles of the balanced scorecard (BSC) by integrating the "project" and "supplier" perspectives to be able to specifically answer to specific needs of the construction industry. Developed conceptual framework was tested with two companies by implementing the framework into companies' strategic review process to identify key performance indicators. The two companies considered the framework interesting and relatively straightforward to complete once the underlying philosophy was realized. However, authors implied that while they were assuming that the developed framework could be the foundation of an "effective project management/measurement for organizations", further testing on larger scale should be done to reach its final iteration.

Various studies introduced performance evaluation models based on balanced scorecard system. Yu et.al. (2007) pointed out to the need of company-level performance assessment and proposed an implementation model based on four perspectives (financial, customer, internal business processes and learning and growth) of balanced scorecard system. Authors summarized twelve performance criteria for assessment, (1) profitability, (2) growth, (3) stability, (4) external customer satisfaction, (5) internal customer satisfaction, (6) market share, (7) research and development, (8) technological capability, (9) business efficiency, (10) human resource development, (11) organization competency, and (12) informatization. Later, Ali et.al. (2013) identified 47 KPIs/success factors categorized under five main perspectives of balanced scorecard system (financial, customer, internal business and learning and growth). Ali et.al. (2016) stated that it is necessary for management to choose suitable and relevant KPIs since excessive number of KPIs can become difficult to handle. Thus, a questionnaire was designed and sent to construction companies to rate the identified KPIs. Results of the questionnaire were used to calculate relative importance index (RII) for each KPI and first 10 KPIs with the highest value was identified, based on the Swan and Kyng's (2004) conclusion that the optimal number of KPIs is between 8 and 12. A framework based on these ten KPIs alongside with measurement methods for them is presented. According to the framework, (1) profitability, (2) growth, (3) financial stability, (4) cash flow, (5) quality of service and work, (6) external customer satisfaction, (7) market share, (8) safety, (9) business efficiency and (10) effectiveness of planning are ten most important KPIs.

Construction Industry Institute (CII) developed CII-BM&M construction project performance benchmark based on several KPIs (CII, 2001). Total of eight KPIs were identified, (1) project budget factor, (2) project cost growth, (3) project schedule factor, (4) project schedule growth, (5) recordable incident rate, (6) lost workday case incident rate, (7) change cost factor and (8) total field rework factor. Like CBPP-KPI (2002), this KPI was also criticized about mostly focusing on project-level performance while having limited effectiveness for evaluating the performance on organizational level (Ahmad et.al, 2016). CII 10-10 benchmark were the latest addition to the benchmarks offered by CII. (1) Planning, (2) organizing, (3) leading, (4) controlling, (5) design efficiency, (6) human resources, (7) quality, (8) sustainability, (9) supply chain and (10) safety were identified KPIs in CII 10-10 (Ahmad et.al, 2016).

Cheung et.al. (2004) proposed an online project monitoring and performance measurement tool named "Project Performance Monitoring System" (PPMS) based on eight "key performance measure categories" which are identified in collaboration with five project management specialists. Identified performance measure categories were (1) people, (2) cost, (3) time, (4) quality, (5) safety and health, (6) environment, (7) client satisfaction, and (8) communication.

Corporation for Technical Development (CDT) established a benchmark system called National Benchmarking system in Chile (Ramirez et.al., 2004). Eleven final performance indicators identified by CDT are: (1) Cost variation, (2) schedule variation, (3) cost of client claims, (4) change in contract sale, (5) accident rate, (6) risk rate, (7) efficiency of direct labor, (8) productivity-performance, (9) rate of subcontract (ratio of subcontracted cost to total project cost), (10) urgent orders and (11) planning effectiveness. Later, Ramirez et. al. (2004) introduced a qualitative benchmark system with an aim to enhance the National Benchmarking System established by CDT, by integrating qualitative management elements alongside these identified performance indicators.

Rankin et.al. (2008) identified twenty-five performance metrics under seven main performance measurement areas alongside with performance collection and reporting methods for construction performance measurement. Rankin's identified main performance measurement areas were: (1) Cost, (2) time, (3) quality, (4) safety, (5) scope, (6) innovation, and (7) sustainability. Rankin et.al. (2008) stated that information about cost, time, safety and safety are easily accessible but detailed interviews with project participants are required to gather information about quality, innovation and sustainability to acquire a holistic view on project performance.

Ngacho and Das (2015) developed a framework for measuring construction performance which is composed of six KPIs and six critical success factors (CSFs) that were identified based on the literature. Identified CSFs are: (1) project related factors, (2) client related factors, (3) contractor related factors, (4) consultant related factors, (5) supply chain related factors, (6) external environment related factors. The identified KPIs are: (1) project time, (2) project cost, (3) project quality, (4) minimum site disputes, (5) project safety and (6) environmental impact. Developed framework also described the relationship between CSFs and their effect on project performance regarding the identified KPIs. According to authors, developed framework enriches the project performance evaluation approach by combining the societal and environmental aspects with the traditional framework which solely focuses on financial perspective.

Ofori-Kuragu et.al. (2016) developed a performance measurement method to be used by contractors to evaluate their project performance based on nine KPIs: (1) client satisfaction, (2) cost, (3) time, (4) health and safety, (5) quality, (6) productivity, (7) business performance, (8) people and (9) environment.

Soewin and Chinda (2018) proposed a multidimensional performance evaluation framework based on 57 relevant performance items that are linked to 10 key factors for construction performance measurement. Identified key performance indicators (KPIs) are: (1) time, (2) cost, (3) quality, (4) safety & health, (5) client satisfaction, (6) environment, (7) financial performance, (8) internal stakeholder, (9) external stakeholder, and (10) information technology & innovation.

Various studies investigated the construction performance measurement methods based on artificial neural network (ANN) models. Alaloul et.al. (2018) proposed an ANN model for the project performance assessment in terms of coordination factors. Total of sixteen performance factors are identified under five main performance factor group which are: (1) planning and scheduling, (2) resource management and contacts, (3) records and documentation, (4) contract implementation and (5) quality and value engineering. Maya et.al. (2021) established an ANN model to forecast the construction project performance based on six performance factors. Identified performance factors are: (1) coordination and commitment of project parties, (2) project team, experience, and availability, (3) schedule estimate, (4) delay in payment of statements, (5) existence of project management software and (6) support from senior management.

2.2. BIM Performance

Increasing adoption rate of BIM implementation in projects paved the way for research on BIM performance. Various studies focused on aspects of BIM, and developed tools and frameworks for assessment of BIM performance and implementation. Succar et.al. (2012) developed a framework based on five specific components that have been developed with the aim of facilitating BIM assessment, namely: (1) BIM capability stages, (2) BIM maturity levels, (3) BIM competencies, (4) organizational scales, and (5) granularity levels. Proposed framework is mostly focusing on BIM assessment based on organizational perspective. In another study, Succar et.al. (2013) highlighted individual competency as "building blocks of organizational capability" and focused on assessment of individual competencies. As a result, a framework called "Individual Competency Index" (ICI) is developed based on five levels of competence ranging from Level 0 (none) to Level 4 (expert).

Barlish and Sullivan (2012) introduced a framework calculation model for benefit focused BIM assessment based on investment and return metrics identified from the literature. Return metrics included request for information, duration improvements, and change orders, while investment metrics included 3D background model creator costs, architectural & engineering costs, contractor costs, and overall savings with BIM in design and construction. Developed model is tested to compare two projects, one of which is BIM based, while the other one did not adapt BIM. Authors suggested effective implementation of real-time tracking metrics to ongoing projects for an optimal assessment. Quantity of RFIs, quantity of change orders, and ratio of cost of change orders to the total project cost are identified as indicators of BIM and project performance.

Nepal et.al. (2014) developed a BIM evaluation framework consisting of four dimensions, namely (1) technology, (2) process, (3) people & organization, and (4) context. Authors contended that addition of context dimension enabled the assessment of issues specific to the projects, and comprehensive and reliable evaluation of BIM is ensured by this addition. Proposed framework is tested on two case studies, and results pointed out to the importance of project-specific limitations, which in return supports authors' argument about the inclusion of project context is necessary.

Tulenheimo (2015) investigated the key challenges that may hinder the success of BIM implementation process, and therefore negatively impact the BIM performance. He identified twenty-three distinct aspects categorized under five main categories which are (1) customer, (2) company, (3) social aspects, (4) technology, and (5) supporting elements. According to the findings, competence, technological infrastructure is important for a successful BIM implementation, therefore affects the BIM performance.

Abdirad (2016) carried out an extensive literature review to identify the metrics that are used for BIM implementation assessment. Figure 3.1. shows identified categories for BIM assessment. As a result of his study, Abdirad (2016) classified over 420 metrics or criteria that are identified in prior research and categorized them under 38 themes. Findings pointed out to a substantial overlap among more than 100 metrics that directly assess the cost and schedule performance of a BIM project. Author also pointed out that the presence of a considerable number of unique metrics underscores the complexity involved in evaluating BIM performance. Abdirad (2016) stated that it is crucial to prioritize metrics in order to establish KPIs tailored specifically to each BIM practice, since evaluating large number of metrics is not feasible.

Kam et.al (2017) proposed a virtual design and construction (VDC) scorecard framework that can be used for assessing BIM performance. Framework is based on four assessment "areas", namely (1) planning, (2) adoption, (3) technology, and (4) performance. These assessment areas are further divided into 10 "divisions" and 56 "measures" defined below them. According to authors, developed framework addresses two limitations found in existing VDC assessment frameworks which are the absence of a comprehensive framework, and inflexible scoring criteria.

Poirier et.al. (2015) proposed an evolutionary approach based on five KPIs to evaluate the BIM implementation process within a specialty contracting small enterprise. Used KPIs were (1) project cost predictability, (2) project scope predictability, (3) productivity indicator predictability, (4) project quality, and (5) project schedule predictability. Proposed approach was tested on eight case studies. Authors stated that when examining the targeted Key Performance Indicators (KPIs) and their corresponding metrics, drawing definitive conclusions about the performance of BIM within the case studies becomes challenging since separating the utilization and impact of BIM from the project context poses a significant challenge. Thus, while some indicators pointed out to improved performance, some did not show distinct trend about performance.

Various studies focused on benchmarking of BIM performance instead of evaluating it, and proposed benchmark models for BIM performance. Du et.al. (2014) argued that existing tools and models about BIM performance are "designed for evaluating instead of benchmarking" and introduced a cloud-based benchmark model tool named "Building Information Modeling Cloud Score" (BIMCS). Developed model is based on twenty performance metrics identified under six categories which are (1) modeling productivity, (2) effectiveness, (3) model quality, (4) accuracy, (5) usefulness and (6) economy. Authors also stated that proposed model has the capability of gathering BIM performance information in an automated manner and store it in a database, to use it as a benchmark reference. According to the study, big data collected in this database can be used to gain a comprehensive understanding of the current state of BIM implementation in the industry and can lead to the development of a BIM performance protocol. Later, Choi et.al. (2018) developed a benchmark system based on twenty metrics identified and categorized under four main metric categories: (1) cost, (2) schedule, (3) dimension, and (4) planning. Although the identified metrics were specifically selected according to healthcare project properties and may not be suitable for various types of projects, authors stated that results of the study may serve as a foundation to achieve a BIM-based benchmarking tool that can be implemented on a large scale in the construction industry.

Effects of development and adoption of BEP on BIM performance has been mentioned in various studies. In their study, Franz et.al. (2019) assessed the impact of BIM use and BIM Execution Plan (BEP) use on project performance based on five project performance metrics identified from the literature, namely (1) construction unit cost, (2) project cost growth, (3) delivery speed of the project, (4) group cohesion, and (5) facility quality. Group cohesion is the combination of "strength of team chemistry", "timeliness of team communication" and "commitment to the project goals" while facility quality refers to the level of satisfaction regarding various aspects of building including structure, environmental systems, and interior finishes. Results showed that BIM use had a positive impact on the construction performance, but the results did not show a meaningful relationship between BEP implementation and performance. However, active involvement in BEP emerged as a substantial indicator in predicting the adoption of BIM use. Yilmaz et.al. (2019) pointed out to the absence of a comprehensive performance assessment model that involves whole life-cycle stages and processes of a construction project and proposed a capability assessment model. Proposed model includes four capability levels and six BIM attributes. Proposed model identified development and adoption of BEP as a BIM standard, and a way of achieving collaboration, which is one of the six identified attributes under the name of "BIM collaboration". Aibinu et.al. (2019) assessed the BIM implementation and argued that complexity and performance of the BIM process may be affected by the impact of "procurement" and "project coordination structure". According to authors, promotion of organizational learning and involving the site manager, suppliers, and subcontractors early on are crucial to enhance the implementation of BIM.

Khanzadi et.al. (2020) investigated the effects of BIM implementation on construction performance in construction stage. During the study, nine sub-criteria were established, and their effects on five construction performance KPIs were investigated. Identified construction performance KPIs were (1) sustainable construction, (2) construction cost reduction, (3) quality improvement, (4) constructability improvement, and (5) time efficient construction delivery. Among the established sub-criteria, project coordination was the one that had the most impact on these KPIs, followed by project schedule and construction sequencing, and clash detection. However, authors pointed out that the test sample size was relatively small and further research and validation based on larger sample size is required.

Luo et.al. (2022) stated that the absence of effective evaluation methods for BIM assessment is the primary reason for limited BIM utilization on Chinese construction industry and proposed a three-stage data envelopment analysis (DEA) approach for BIM performance assessment. Developed DEA approach is based on ten performance indicators under five main "evaluation layers", namely (1) talent pool, (2) capital reserve, (3) technical level, (4) enterprise level, and (5) economic level. Authors pointed out that these indicators may not be enough to carry out a complete assessment of BIM and should be supplemented with additional indicators focusing on various other perspectives.

2.3. Big Data and BIM

It becomes challenging to "manage, control and analyze" the data since the data is rapidly getting bigger in size, and becoming increasingly diverse (Al-Mekhlal and Khwaja, 2019). While total amount of data produced by humanity was equal to 5 exabytes in 2003, this number increased to 2.72 zettabytes (10^{21} byte) in 2012 (Sagiroglu and Sinanc, 2013). Predictions and forecasts indicate that this number will continue to increase exponentially and reach 120 zettabytes in 2023 and 181 zettabytes in 2025 respectively (Statista, 2023). There is a common misconception about defining big data by the size of the data alone (Katal et.al., 2013). Several studies identified various characteristics of big data. Among these identified characteristics variety, velocity, and volume were the most frequently ones and called as "3Vs" (Al-Mekhlal and Khwaja, 2019). "Variety" implies that data originates from multiple sources and encompasses diverse categories including structured, semi-structured and raw data. Presence of extensive amounts of data is indicated by "volume". "Velocity" indicates the rate at which data is received from multiple sources.

Big data provides several benefits for wide range of industries and sectors including manufacturing industry, public sector, healthcare sector, retail sector and construction industry. (McKinsey,2011). Identified benefits of the big data is including but not limited to improving productivity, increased operational efficiency, better customer service, enhanced customer experience, informing strategic direction. Munawar et.al. (2022) stated that several studies show construction industry employed big data for several purposes including failure prediction data, analysis of construction waste, profitability data, and modular and prefabricated construction. Authors identified the primary objective of employing big data in construction industry as achieving improved project planning and accelerated construction process by forecasting the possible timelines for specific project and identifying key improvement areas and factors to enhance the whole process. Big data utilization supported by different machine learning (ML) techniques and computational models provides advantages in controlling costs, timelines, and human resources in a construction project. Munawar et.al. (2022) also pointed out to the enhanced automation and safety planning and management can be achieved by combining big data, machine learning (ML) and artificial intelligence (AI).

Big data concept introduced problems about data management and analysis alongside with it. Japec et.al. (2015) stated that managing and analyzing big data requires the implementation of new processes. Tsai et.al. (2015) argued that conventional ways of data analysis may be incapable of dealing with large amount of data introduced with big data. Therefore, new data analysis methods and frameworks have begun to be developed that will enable the analysis of big data. Tsai et.al. (2015) carried out a comprehensive investigation about big data analysis frameworks and methods and identified thirty-two unique methods and frameworks under two main perspectives: (1) analysis frameworks, and (2) mining algorithms. Identified methods were based on various techniques, including parallel computing platforms, machine learning algorithms, classification techniques, clustering techniques, and frequent pattern techniques.

Various studies explored the ways of using big data with BIM. Huang (2021) investigated how BIM big data can be used for construction cost management practices. He stated that information from the BIM model can be extracted and used to create a big data database, and by using this BIM based big data for cost management, several benefits can be realized throughout the stages of a construction project. During the investment decision-making process, "unpredictable cost", which refers to additional costs due to unforeseen factors that cannot be determined while using traditional management practices based on two-dimensional drawings, can be lowered with usage of BIM based big data. For bidding process, disputes arising from absent items in the bill of quantities or miscalculation of the bill of quantities can be dramatically decreased by utilizing BIM based big data usage. In construction stage, utilization of BIM and big data technology can improve communication, reduce the amount of rework and conflicts, and prevent the construction schedule from delays, which positively effects the cost management.

Various studies investigated the ways of combining big data and BIM for effectively reducing the construction waste. Reducing the waste contributes to improving the environmental performance of the construction project. Bilal et.al. (2015) stated that because of the BIM's ability to store and process vast amounts of data, big data technologies are "inherently suitable for BIM". Later on, Bilal et.al. (2016) proposed a big data framework to analyze the construction waste. Proposed framework is a part of construction waste analysis tool based on BIM, which can be used to "provide waste analytics with interactive visualization".

Chen et.al. (2016) developed a cloud-based framework system to collect and store BIM big data. Wide range of analyses can be carried out efficiently on stored big data thanks to by virtue of included four data processing types in the developed framework.

CHAPTER 3

METHODOLOGY

Methodology of this thesis is explained in this chapter in detail. Main objective of this thesis was evaluating BIM performance of a project from main contractor view based on a big data from a construction project. To achieve this objective, case study method is used. A retrospective case is selected and used to test proposed systematical approach. In chapter 3.1., definition of case study alongside with its strengths and weaknesses are presented. Chapter 3.2. shows the detailed steps of research methodology used in this thesis.

3.1. Definition, Strengths and Weaknesses of Case Study Method

There are several definitions for the case study. Yin (2018) provided an all-inclusive twofold definition for case study, including its scope and features. According to him, case study can be defined as an empirical method that examines a contemporary phenomenon, which is referred as case, thoroughly and within its real-world context. His definition's second part focuses on features of a case study:

> A case study copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result benefits from the prior development of theoretical propositions to guide design, data collection, and analysis, and as another result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion.

Case study research proposes an extensive form of inquiry, including unique design principles, data gathering techniques, and particular data analysis approaches (Yin, 2018). Flyvbjerg (2006) argues there is a common misunderstanding that case studies are only practical for hypothesis generation, and states that case studies are practical not only for both hypothesis generation and hypothesis testing for also for a wider range of research activities. Case studies can be used for exploration, theory building, theory testing, theory extension and refinement, and description apart from hypothesis building and testing (Ebneyamini and Sadeghi Moghadam, 2018).

There are several advantages of the case study method according to the literature. One of the biggest advantages of the case analysis method is that it allows to use both qualitative and quantitative data collection methods together (Eisenhardt, 1989). Case studies are also well-suited for answering “how” and “why” questions and can be used to explain complex real-life like organizational and managerial processes from a holistic view (Yin, 2018). Lindvall (2007) pointed out to ingle case study method and argued that its most evident advantage is yielding in-depth analysis about the specific case.

Case study method also criticized in the literature and few disadvantages of it are identified. Various studies argued that case study method prone to being subjective and biased (George and Bennett, 2005; Yin, 2018). Lack of rigor caused by not following the systematic procedures (Yin, 2018), difficulties on generalization (Stake, 1978), validity problems (Yin, 2018), and necessity of significant time investment (Yin, 2018) are other disadvantages of case studies stated in the literature.

Case demonstrated in this study is a retrospective case. Retrospective case means that “data is collected after the events and activities under study have already occurred” (Mills et.al., 2010). In retrospective studies, researcher aims to gain insight into past events or their outcomes by utilizing the historical data.

3.2. Research Steps

In the case study, primary focus was collecting and analyzing qualitative and quantitative data from main contractor. Rather than collecting and analyzing data from various project phases, this thesis focused on the data from construction stage. Data collection includes raw project data that is given by main contractor, and the data gathered from interviews with main contractor. Collected raw project data is overviewed PowerBI to identify its content and to derive possible analysis metrics from the data. Following that, a framework for evaluating the BIM performance is developed. Developed framework includes eleven data parameters and nineteen performance metrics identified from the combination of data from an extensive literature review about BIM and construction performance, interviews with main contractor, and an overview of the raw project data provided by the main contractor. Following the development of the evaluation framework, collected raw project data is analyzed according to the identified metrics and data parameters in the framework. Data parameters that can be used for analysis were specifically identified for different types of raw project data. During the data analyses, raw project data is categorized and filtered according to the identified data parameters and analyzed following the identified performance metrics. Follow-up interviews are done with contractor firm to verify the analyses results, and to identify performance problems and benefits that cannot be detected by using the raw data alone. PowerBI is used for the analyses of raw project data. There are several reasons for choosing PowerBI, including its compatibility with excel files (Krishnan, 2017), extensive support for "a wide range of statistical analysis and querying operations" (Carlisle, 2018), and its ability for data retrieval, cleaning and visualization (Becker and Gould, 2019). Raw project data is imported to PowerBI, and later cleaned and filtered for data analysis based on identified performance metrics. During the performance evaluation process, additional interviews are conducted with the main contractor to discuss and verify the results of the data analyses in PowerBI, and to identify effects of BIM implementation on identified performance metrics. Figure 3.1. shows the flowchart containing steps of research methodology used in the research.

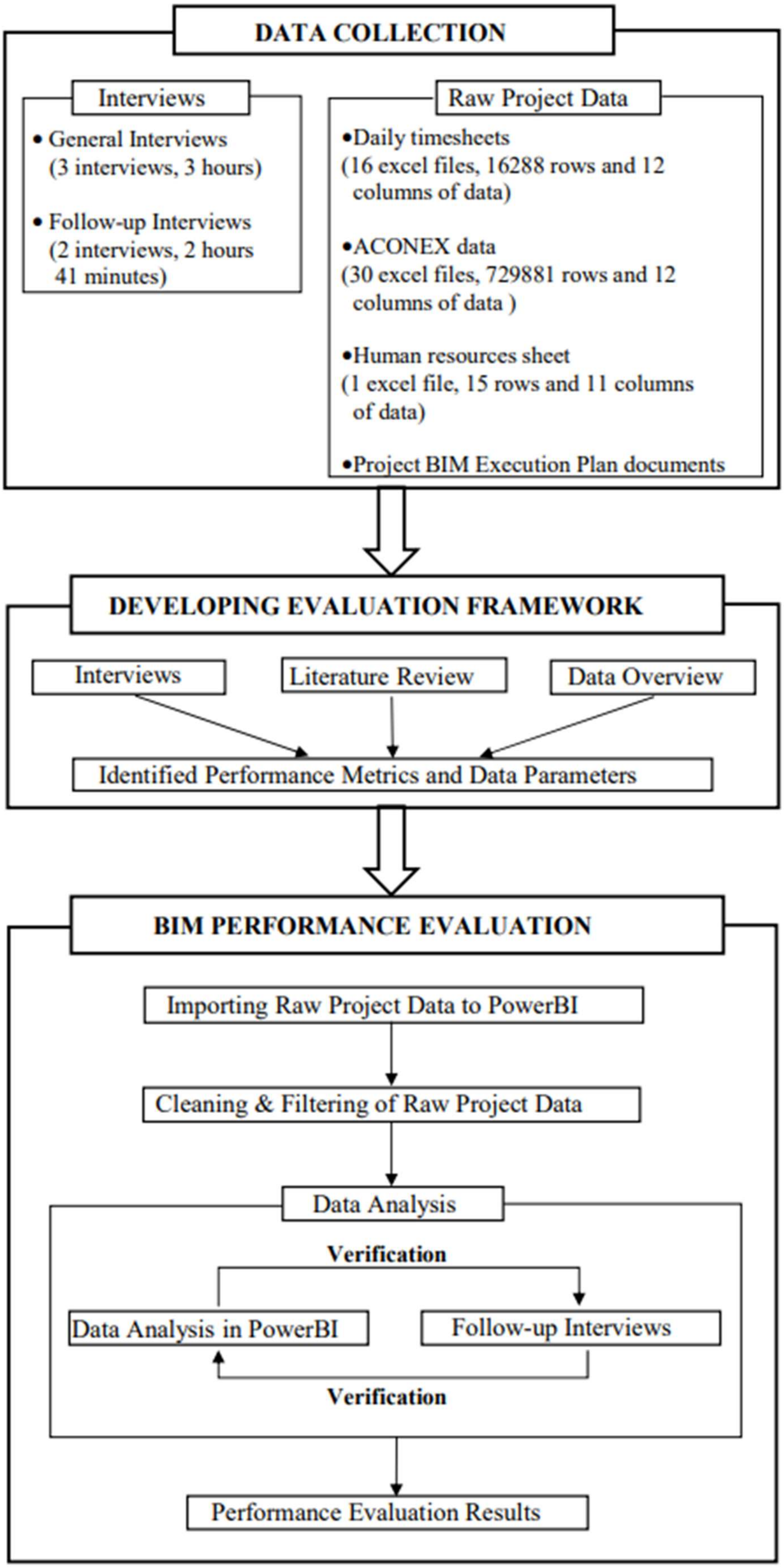


Figure 3.1. Flowchart showing the steps of research methodology used in the research.

3.2.1. Identification of Metrics and Parameters for BIM Performance Evaluation

Before starting data analyses, a framework is developed by using performance metrics identified from the literature, data overview, and interviews with the main contractor firm. Total of nineteen performance metrics were identified and categorized under six main categories: (1) time, (2) out of scope tasks, (3) drawing revision numbers, (4) organization & people, (5) BIM process and (6) technology. These performance metrics are used to analyze BIM performance based on raw project data, interview data and project BIM Execution Plans. Table 3.1. shows identified performance metrics to be used for BIM performance analysis.

Table 3.1. Identified performance metrics to be used for BIM performance analysis.

	Identified Performance Metrics
Time	Time spent based on discipline
	Time spent based on task classification
Out of Scope Tasks	Ratio of time spent on out of scope tasks to overall time spent
	Impact of out of scope tasks on employee cost
Drawing Revision Numbers	Average revision number required for drawings to be approved for each discipline
Organization & People	Implementation of BEP
	Roles, responsibilities and goals identified in contract
	People's resistance to change
	Subcontractor's BIM competency
BIM Process	Variety of communication methods and effective use of them
	Effective BIM coordination between stakeholders
	Effective clash detection
	Effective quality control
	Presence of construction scheduling and sequencing
	Properly defined information exchange methods
	Effective usage of BIM model for both drawing and modeling processes
	Design changes
Technology	Technological infrastructure (Hardware&software)

The data parameters used during data analysis were determined specifically for each data type. There were total of eight different data parameters identified for three different data types (human resources data, daily timesheet data and ACONEX data).

Some of these specified data parameters are common to more than one data type, e.g., employee name is a common identified parameter for both human resources data and daily timesheet data. Eleven identified parameters are: (1) Employee name, (2) discipline, (3) task classification, (4) building name, (5) hours spent, (6) employee total cost, (7) drawing revision number, (8) drawing status, (9) task brief description and (10) date modified and (11) revision date. Table 3.2. shows which data parameters are identified to be used during the analysis of different data types.

Table 3.2. Table showing identified data parameters and data types in which these identified parameters can be used for analysis.

Data Parameter	Data type in which identified parameter can be used for analysis
Employee name	Daily timesheet data, Human resources data
Discipline	Daily timesheet data, ACONEX data
Task classification	Daily timesheet data
Building name	Daily timesheet data, ACONEX data
Hours spent	Daily timesheet data
Employee total cost	Human resources data
Drawing revision number	ACONEX data
Drawing status	ACONEX data
Task brief description	Daily timesheet data
Date modified	ACONEX data
Revision date	ACONEX data

Table 3.3. shows references of the identified performance metrics in the developed framework showing, alongside with the degree of connection between identified metrics and the references from the literature. Indirect relation means the identified metric in the framework can be correlated as a result of another identified metric in given reference. Thirteen of the identified metrics have relationship with the identified metrics from the literature to some degree, while five of them is uniquely developed from the results of interview and overview of the raw project data. These five metrics are (1) time spent based on discipline, (2) time spent based on task classification, (3) ratio of time spent on out-of-scope tasks to overall time spent, (5) impact of out-of-scope tasks on employee cost, (5) average revision number required for drawings to be approved for each discipline and (6) average approval duration for each revision number.

Table 3.3. Table showing the references of identified performance metrics in developed framework for data analysis.

		References from the literature																	
	Identified Performance Metrics	Du et.al. (2014)	Soewin and Chinda (2018)	Abdirad (2017)	Yilmaz et.al. (2019)	Khanzadi et.al. (2020)	Alaloul et.al. (2018)	Maya et.al. (2021)	Aibinu et.al. (2019)	Cheung et.al. (2004)	Franz and Messner (2019)	Nepal et.al. (2014)	Tulenheimo (2015)	Kam et.al. (2017)	Poirier et.al. (2015)	Luo et.al. (2022)	Barlish and Sullivan (2012)	Ngacho and Das (2015)	Reenu et.al. (2017)
Time	Time spent based on discipline																		
	Time spent based on task classification																		
Out of Scope Tasks	Ratio of time spent on out of scope tasks to overall time spent																		
	Impact of out of scope tasks on employee cost																		
Drawing Revision Numbers	Average approval duration for each revision number																		
	Average revision number required for drawings to be approved for each discipline																		
Organization & People	Implementation of BEP				Strong		Indirect				Strong								
	Roles, responsibilities and goals identified in contract			Moderate			Strong	Indirect	Moderate	Strong		Strong						Indirect	
	People's resistance to change			Moderate									Strong						
	Subcontractor's BIM competency		Strong	Moderate	Moderate			Moderate	Indirect	Moderate			Moderate					Moderate	Strong
BIM Process	Variety of communication methods and effective use of them		Strong	Strong			Strong			Strong	Moderate	Moderate		Indirect		Moderate	Indirect		Strong
	Effective BIM coordination between stakeholders		Strong	Strong		Strong		Strong	Strong	Strong		Strong		Moderate		Moderate	Indirect	Moderate	
	Effective clash detection	Strong		Moderate	Strong				Strong				Indirect						
	Effective quality control		Strong	Strong		Strong	Moderate	Strong	Moderate										Strong
	Presence of construction scheduling and sequencing					Strong	Moderate										Indirect		
	Properly defined information exchange methods				Strong				Moderate			Strong		Indirect					
	Effective usage of BIM model for both drawing and modeling processes				Strong														
	Design changes		Strong						Moderate	Strong						Strong	Moderate	Strong	
Technology	Technological infrastructure (Hardware&software)		Strong	Strong	Moderate				Strong			Strong	Moderate	Moderate					Moderate

Strong Relation — Moderate Relation — Indirect Relation

CHAPTER 4

RETROSPECTIVE ANALYSIS OF BIM PERFORMANCE IN A CONSTRUCTION PROJECT

This chapter focuses on the retrospective analysis of BIM performance on a case study of a construction project from the view of a main contractor. The main contractor in this project is a leading firm with 20 years of experience in sector, constructing smart buildings, airports, and airport-related facilities, operating in 14 countries. Main contractor is rated in the "World's Top 250 International Contractors List" (ENR, 2022). Sub-contractor, designer, client name and case study project name are kept secret during the case study. The chapter outline is as follows: 4.1 provides a general overview of the case study project, 4.2 describes BIM implementation for the project, 4.3 provides insights on the project data analysis, 4.4 includes interview data in relation with the project data analysis, 4.5 includes discussion of the results.

4.1. General Overview of the Case Project

Case project is a construction project in Dubai city, which is located on the Persian Gulf coast of the United Arab Emirates. The project is a residential building complex in the city center which includes luxury residences, serviced apartments and different types of facilities. Project's target audience is high income level users. One of the distinct characteristics of the project is that it has a multinational stakeholder structure. During the project, stakeholders from multiple countries worked together. Main contractor of the project is a Turkish firm which is operating in multiple countries across the world and listed in Engineering News Record's "World's Top 250 International Contractors List" (ENR,2022). Project is composed of two plots, A2A3/A1a and A4/A1b. These plots can be thought as individual projects that started and ran simultaneously. A2A3/A1a plot includes two serviced apartment towers, A2 and A3, with 62 and 54 stories respectively, and their facilities including gym, swimming pools and communal areas. Towers include 1-, 2-, and 3-bedroom apartments with upper floors containing 4- and 5-bedroom penthouses. Parking needs are met by a 5-level underground parking with a capacity of nearly 1000 vehicles. Development area in this plot is 213110 square meters, including all the facilities in podium area. A4/A1b includes A4 tower, which is a luxury residential tower that is containing residential units ranging from one to five bedrooms, generally with multiple balconies and second service entrances. A4 tower is consist of a seventy-eight story with a mix of single and double unit floors, four story podium that is containing an entrance lobby, quest quarters, landscaping and various high end tenant amenities, and six basement levels underneath the podium, providing more than four hundred parking spaces for the tower and podium. A1b is a Roads and Transport Authority (RTA) right of way, which is consist of a shared basement, a road and drop off to A4, basement ramp entrance and landscaping. Development area in this plot is 134163 square meters, including A4 tower, basement/podium and A1b RTA. Table 4.1. shows project information for each project plot.

Table 4.1. Project information about A2A3/A1a (top) and A4/A1b (bottom) plots.

	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms	Duplex	Total Units	GFA (m^2)	BUA (m^2)
A2A3/A1a Plot									
A2 Tower	82	202	116	2	5	-	407	58039	70268
A3 Tower	53	260	137	2	7	-	459	67831	80506
Basement/Podium	-	-	-	-	-	-	-	6457	62336
Total	135	462	253	4	12	-	866	**132327**	**213110**
A4/A1b Plot									
A4 Tower	-	-	-	104	12	3	119	80808	96396
Basement/Podium	-	-	-	-	-	-	-	10180	33576
A1b	-	-	-	-	-	-	-		4191
Total	-	-	-	104	12	3	119	**90988**	**134163**

Different design approaches and design decisions resulted in major differences in floor plans between towers in A2A3/A1a and A4/A1b plots. Figure 4.1. schematically shows the project design and relationships between different project plots and different towers. On A4/A1b plot, all main floors with units apart from duplex ones on top are indicated as “typical floor” while on A2A3/A1a plot three different floor plan indications can be seen. These different floor types are “typical floor”, “slanted column” and “similar design, slanted column”. Due to presence of slanted columns and columns getting smaller on upper floors, available area on each floor was different. This situation combined with owner’s desire to use all available area led to constant design changes on each floor, which affected the project’s BIM performance negatively by increasing the total cost and time spent on the project. Reasons of the constant design changes and their effects on the

BIM performance are explained in detail in “Data Analysis in PowerBI” (Section 4.3.2) and “Interviews with the Main Contractor Firm” (Section 4.4) sections.

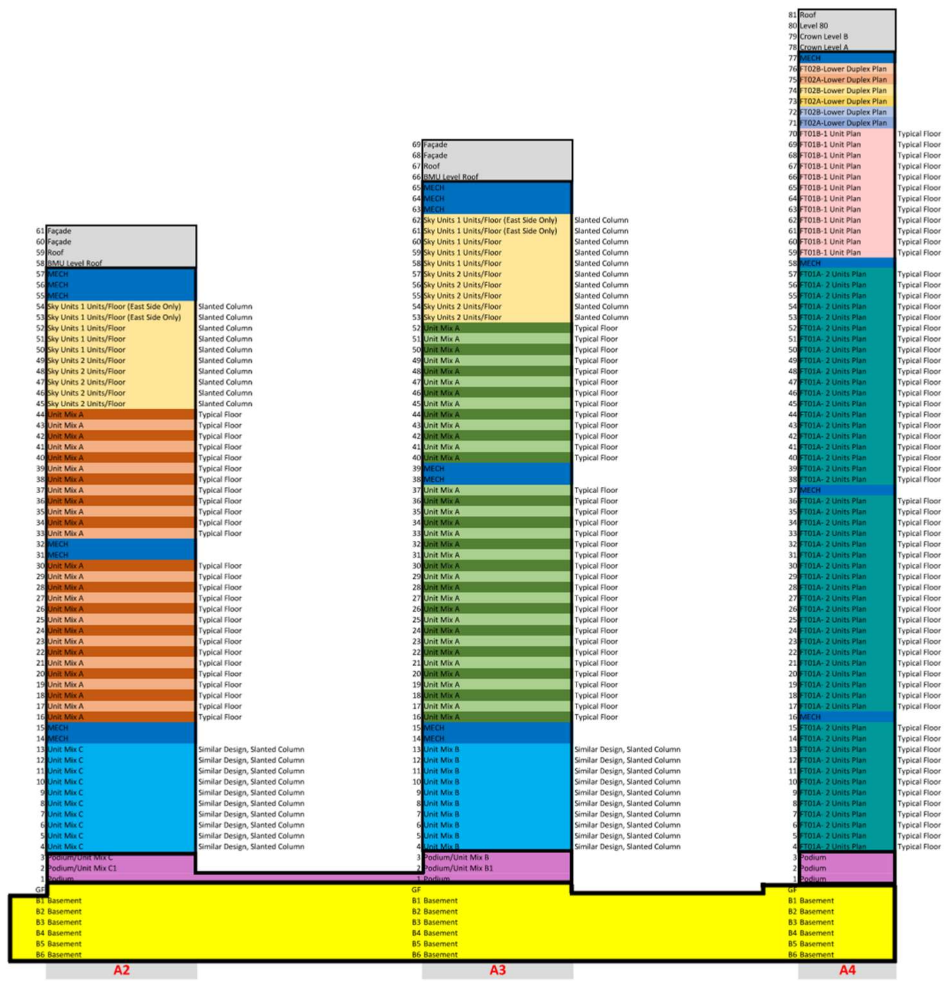


Figure 4.1. General project overview showing relationships and connections between towers and project plots.
(Source: Projects' BEP documents)

4.2. BIM Implementation in the Project

BIM usage was mandatory for both design and construction phases of the case project. During the project, BIM was used for all works including but not limited to design coordination, site coordination, site logistics management, clash detection, quantity takeoff, design management, shop drawing production and design development works.

Case project investigated in this study adopted the traditional linear “design-bid-build” contract approach. Design phase of the project started several years before main contractor being involved in the project. Designer firms were different for each plot and were responsible from authoring the design BIM models, production of IFC drawings and providing design updates and bulletins throughout the project. During the design stage, design of the project changed several times. In that period, not only the design but also the designer firm has changed on A2A3/A1a plot, while on A4/A1b plot designer firm stayed the same. On A2A3/A1a plot, prior designer firm had the interior design done by a Spanish interior design firm and coordinated the Spanish firm’s interior design with their part of design. The new design firm on A2A3/A1a plot, which continued to work on the project until the end of it, had to redo the design from the ground up because of major changes in design approach and design decisions. During this redesign period, new designer firm did not carry out necessary coordination between the old interior design done by the old interior design firm and new design done by the new designer firm. There were mismatches between the interior design, which is done by the old interior design firm according to the old design, and rest of the design since proper coordination and design updates were not made. This situation and its effects on BIM performance in the project is explained in more detail in “Data Analysis” (Section 4.3) and “Interviews with the Main Contractor Firm” (Section 4.4) sections of the study.

Main contractor firm joined the project after the “bid” part and prior to the beginning of the construction phase, with their main role corresponds to the “build” part of the contract. Main purpose of the main contractor is overseeing the all the construction and delivery process in the construction stage. Raw data that was used for analyses in this study is from the BIM department of main contractor firm. Main purpose of the main contractor firm’s BIM department was production of shop drawings. However, since the design on both plots kept changing even during the construction stage, they also had to help with the design works, which resulted in additional workloads and responsibilities.

In interviews, BIM manager of the main contractor firm stated that while main contractor was responsible from the "build" part of the project's traditional "design-bid-build" contract type, because of the aforementioned continuous design changes and additional design responsibilities, main contractor had to act like as if they were participating in a "design-build" type contract. Figure 4.2. shows the key parties involved in the project. There are six key parties in project: project management, lead consultants (one for A2A3/A1a, one for A4/A1b), main contractor and three subcontractors (one MEP, one façade and one steel works). From this point on, plot A2A3/A1a is referred to as A2A3 and plot A4/A1b is referred to as A04 for simplicity.

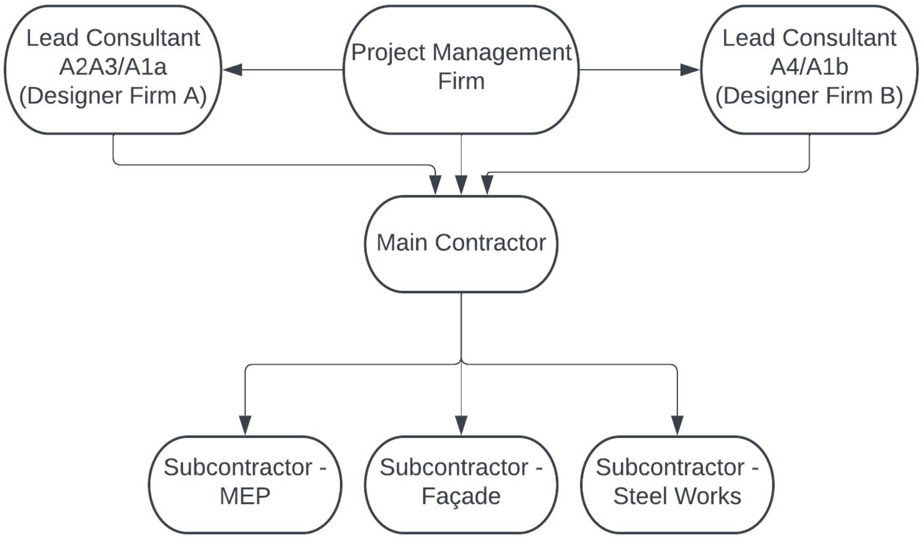


Figure 4.2. Key parties in the project. Note that there are two lead consultants as a result of each plot having its own designer firm.

4.2.1. Analysis of BIM Execution Plans

In this section, BIM implementation on the project is explained in detail through an in-depth review of the BIM Execution Plans of A2A3 and A04 plots. Information from this section is used as a reference together with the results of the data analysis (Section 4.3.) and interviews (Section 4.4.) to evaluate the BIM performance in the project.

Successful BIM implementation is a must to ensure the success of a BIM project. BIM Execution Plan (BEP) plays an important role in successful BIM implementation. McPartland (2018) states that "The success of your BIM project is down, in no small part, to developing an effective BIM Execution Plan". According to GSA (2016), "the intent of the BIM Execution Plan (BEP) is to define a foundational framework to ensure successful deployment of advanced design technologies on your BIM enabled project". BEP contains information on every aspect of BIM implementation including but not limited to processes, goals, used software, communication and information flow, responsibilities of project participants and planning. Reducing unexpected issues, amount of rework, "redundancies" and eliminating the "gaps in the flow of model-based information" by effective planning of all of the project phases from design to construction alongside with "optimizing work and model flow across the project" are the goals of BEP (GSA, 2019). Comprehensive investigation of BEP may reveal information about BIM performance in the project. Thus, with the help of BEP, BIM implementation in this project is examined in detail under three identified main categories: (1) organization, (2) process, and (3) technology. Organization category includes roles and responsibilities and organizational structure of the BIM implementation. Process category includes BIM workflow and details about how coordination and scheduling achieved in project using BIM. Technology category includes programs and methods used for different purposes like modeling, communication, and file transfer. Figure 4.3. shows identified main categories that is used to examine the BIM implementation in the project. While BIM implementation without the usage of BEP is possible, usage of BEP effects the BIM implementation and performance positively. BEP defines the BIM implementation, but also well detailed and fully executed BEP is required for the success of BIM implementation, therefore for the success of the project. As stressed in BIM performance chapter in the literature review (Chapter 2.2), several studies stated that usage of BEP is required for optimal BIM performance and BIM implementation (Franz et.al, 2019; Yilmaz et.al., 2019) Therefore, in the proposed schema, BEP is placed not only as definer of BIM implementation, but also as a requirement for successful BIM implementation.

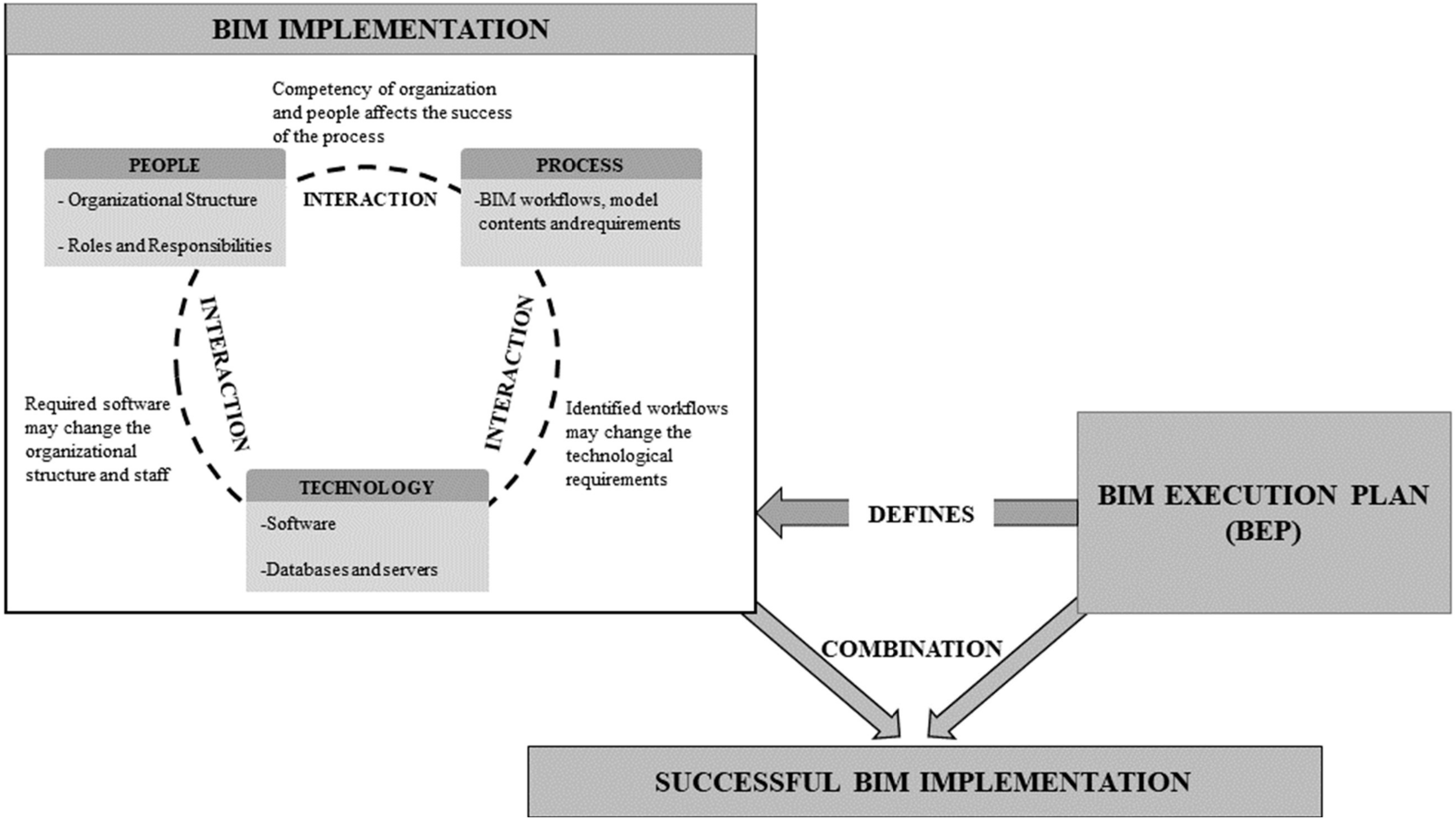


Figure 4.3. Main categories identified for BIM implementation and relationship between BIM implementation, BEP and success criteria.

4.2.1.1. Organization

In this section, organizational structure of BIM implementation in the project such as the roles and responsibilities of project participants is examined. Main contractor firm was responsible from all construction and delivery processes during the construction stage. BIM implementation and management was one of their many responsibilities. Main contractor firm was responsible from the design management, design coordination, BIM management and shop drawing management during the BIM implementation. Validation of shop drawings and models, coordination models and reviews, creation of clash detection reports within each discipline and among different disciplines, development and implementation of BEP are carried out by main contractor firm during the project. BIM models and shop drawings are created by main contractor and sub-contractors. Creation of design BIM models and IFC drawing production were responsibilities of designer companies.

Project is divided into two plots (A4/A1b and A2/A3/A1a) and each plot had different designer company. Figure 4.4. shows project's BIM organizational structure. Organizational structure in the figure is divided into two parts according to the BIM workflow in the project so that responsibilities of the employees can be understood more easily. These parts are "coordination and compile" and "modeling and drafting". Each project plot had its own MEP manager, MEP BIM coordinator, senior design architect and senior structural engineer while BIM manager, architectural BIM coordinator, structural BIM coordinator, structural manager and engineering manager are same on both plots. This complexity, combined with presence of different designer firms and management differences between these firms led to a number of challenges during the project. Such challenges are explained in more detail in Chapter 4.4. Interviews part of this document. BIM coordinators were responsible for the review of native BIM models prior to issuing for acceptance into the federated model. They were also responsible from BIM document control, producing and publishing clash reports, management of coordination reviews and ensuring that subcontractor models fulfill the project BEP requirements. BIM manager was responsible for compilation and management of federated model, editing and managing BIM Execution Plan and the Model Production Schedule, and ensuring the use of BIM across the project.

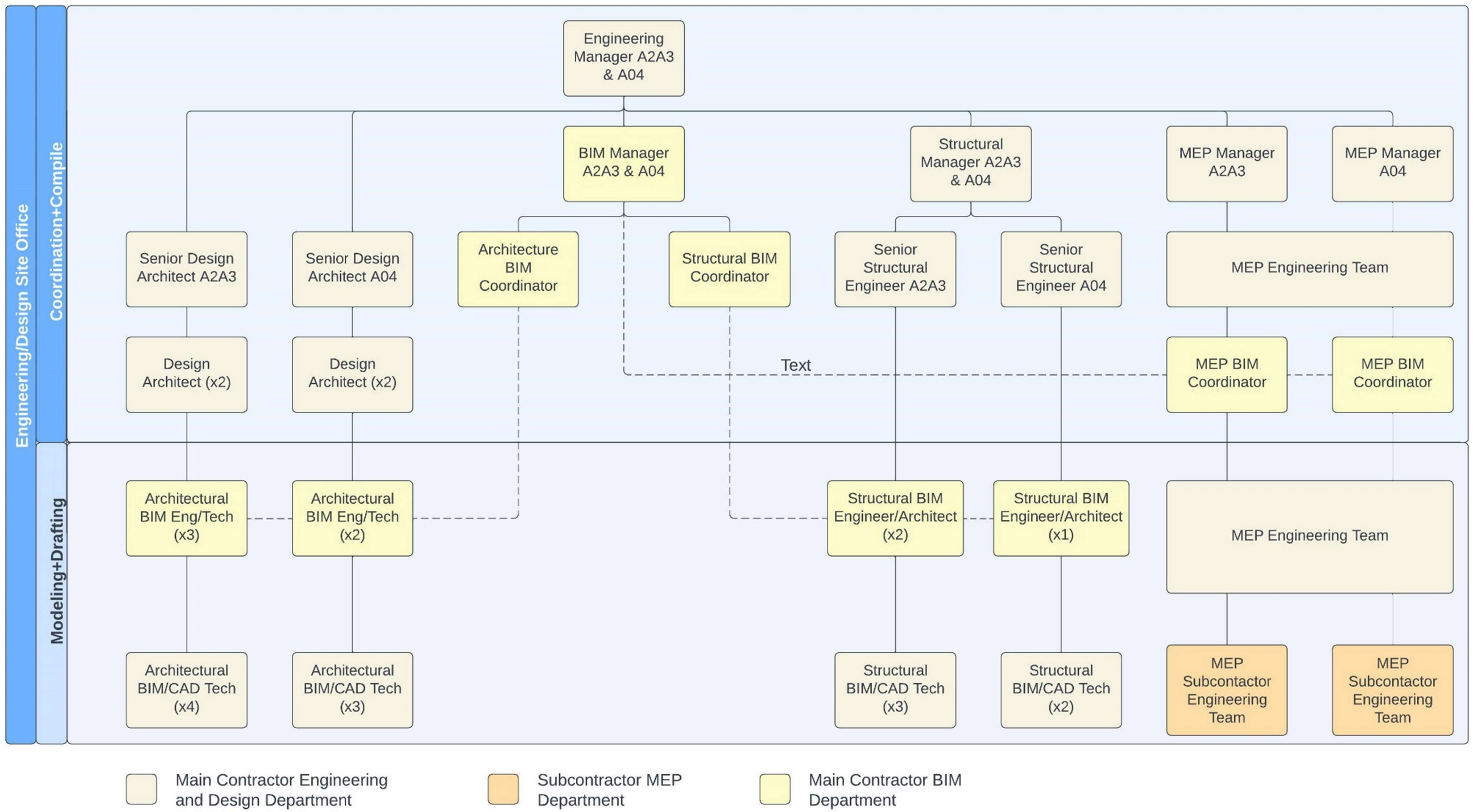


Figure 4.4. Organizational structure showing employees and from which part of the workflow they are responsible.
(Source: Projects' BEP documents)

4.2.1.2. Process

In this section, parts of BEP that having potential of being linked with projects' overall BIM performance are examined under following subheadings: (a) RFI management process in BIM workflow, (b) model based drawing production process, (c) clash detection level of definition, (d) level of development, (e) non-conformance to quality control measures in quality control processes, (f) means of coordination, and (g) construction scheduling and planning workflow are examined. These parts are selected based on identified performance evaluation metrics in Section 3.2.1.

RFI Management Process in BIM Modeling and Coordination Workflow

BIM modeling and coordination workflow is defined in project's BEP. Modeling procedures and how to handle collection BIM models from all participants, carrying out clash tests and delivery of results are all detailed in BIM modeling and coordination workflow. Figure 4.5. shows BIM modeling and coordination workflow in the project. BIM workflow includes two key parties, client, and contractor, and divided into two phases, modeling, and coordination. Request for Information (RFIs) played an important role in BIM workflow. RFI is a written tool used by project participants to formally request additional information or seek resolution or clarification regarding various matters on design, construction, and other contractual documents (Hanna et.al, 2012). Before moving into the next stage, it was checked whether there was an RFI raised, and the next stage was not started without making necessary actions taken according to the raised RFI's. These RFI's along with other issues is reviewed by project stakeholders in design coordination meetings and weekly coordination meetings. Main contractor and subcontractors are responsible to apply resolutions for these RFI's, which can be delivered in the form of RFI responses or engineering instructions. Herrera et.al. (2019) and Chen et.al. (2018) identified number of RFIs prior to construction during the end design and number of RFIs during the actual construction process as performance metric. Chen et.al. (2018) stated that increased number of RFIs pre-construction stage resulted in reduced number of RFIs during the construction, thus increased the performance by reducing the number of change orders and rework. Proposed workflow in the BEP focuses on raising all potential RFIs before construction, therefore should improve project performance as suggested by Chen et.al. (2018).

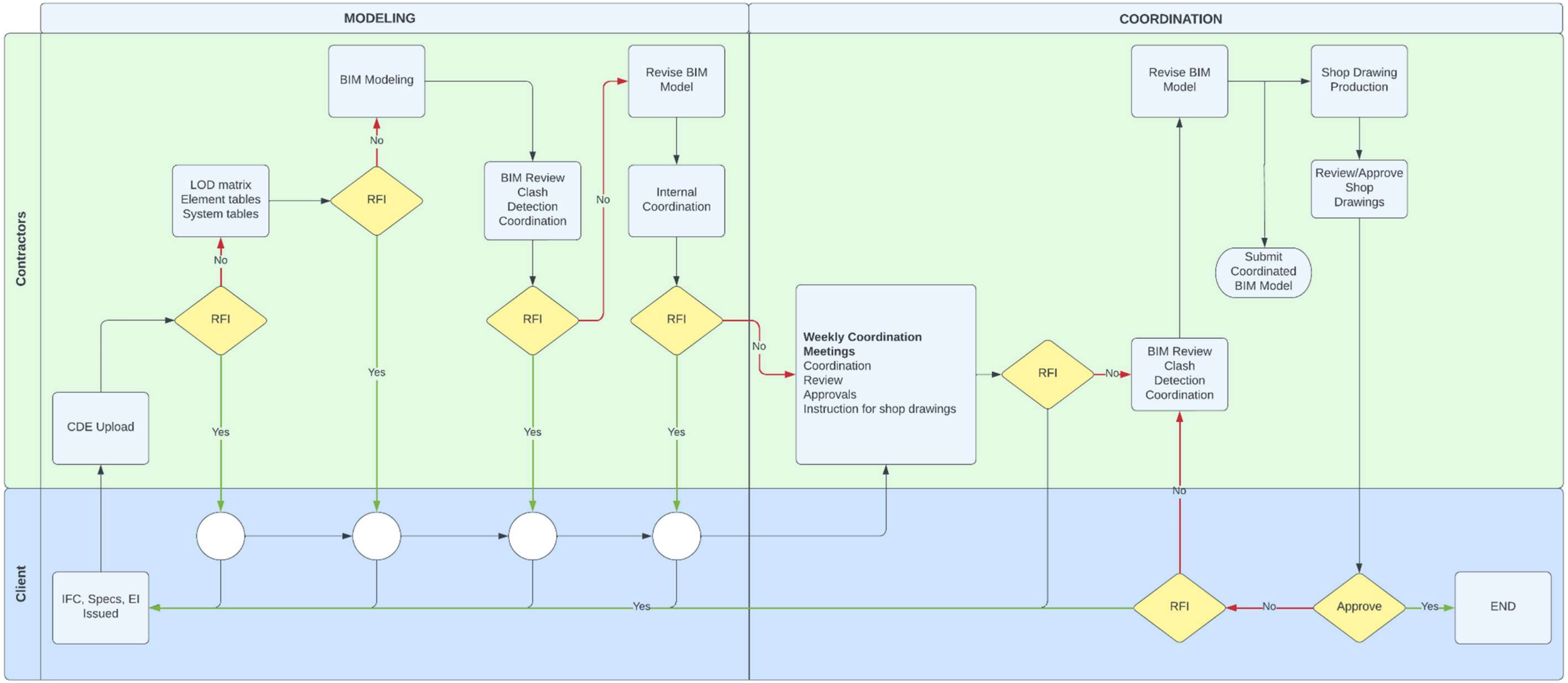


Figure 4.5. BIM modeling and coordination workflow in the project. RFI's have an important role in the workflow, before moving into the next stage, it is first checked whether there is an RFI raised. In case of RFI/s present, next stage cannot begin before applying a resolution to the raised RFIs.

Model based Drawing Production Process

"Effective usage of BIM model for both drawing and modeling processes" is one of the identified metrics in the developed evaluation framework. Findings from the projects' BEP review are in line with the requirements of this metric. According to the BEP document all plan views, sections and elevations should be exported straightly from 3D models. Dimensioning, tagging and annotations carried out directly on plan views that are associated with 3D models. According to the BEP of the project, accurate 2D drawings that are meeting the CAD standards can be pulled from 3D models if the templates are precise. This process results in advantages like ease of update for 2D drawings when there are model changes, and producing 2D drawings that are exactly matching 3D models. There are three identified categories for drawings in the project: 1) Revit, 2) Revit & AutoCAD and 3) AutoCAD. Drawings that are produced directly in Revit are categorized as Revit category. Drawings that are produced from the model and specified more in detail in AutoCAD are categorized under the Revit & AutoCAD category. Drawings that are produced explicitly on AutoCAD are categorized under the AutoCAD category. Vast majority of project drawings belong to categories 1 and 2. While defined drawing production process met the requirements of the "Effective usage of BIM model for both drawing and modeling processes" performance metric, problems arose during the implementation of drawing production process, which effected the BIM performance negatively. These problems and their reasons are explained in detail in "Data Analysis" (Section 4.3) section.

Clash Detection Level of definition

"Effective clash detection" is another identified metric in the developed evaluation framework (Section 3.2.1). Therefore, clash detection requirements and processes in the project is investigated in detail. Clash detection process are defined in both project BEPs. In both BEPs, weekly BIM submissions are required to provide a "federated model" including clash tests inside them. Federated models are BIM models that are created by merging BIM models from various disciplines (structural, architectural, MEP) into a single model (Autodesk,2018). According to BEP, federated models compiled from accurate BIM models are required to provide best possible platform for collaborative working during the delivery of the project. BIM coordinators were responsible for reviewing native BIM models prior to issuing for acceptance into the federated model. The BIM manager was responsible for compilation and management of the federated model and the development of clash strategy processes. Clash tests and reports were conducted by BIM coordinators. BIM authoring leads were also engaged in clash detection process. There were four BIM authoring leads on the project; structural modeling lead, architectural modeling lead, mechanical subcontractor lead and electrical subcontractor lead.

For A2A3, clash detection process is identified as two different main categories; (1) discipline-wise clash detection and (2) interdisciplinary clash detection. These two main clash detection categories are further separated into three sub-categories as indicated in Table 4.2. below. Clash detection matrix categories for A2A3 buildings can be evaluated as being not comprehensive as A04 building's when information on Table 4.2 and Table 4.3 are compared. The effect of such different levels of detail clash detection process planning will later be discussed in Section 4.4 and Section 4.5.

Table 4.2. Clash detection categories according to A23's BEP.

Discipline-wise Clash Detection		Interdisciplinary Clash Detection	
Architectural	Architectural	Structural	MEP
MEP	MEP	Architectural	MEP
Structural	Structural	Architectural	Structural

For A04, clash detection process is more detailed compared to A23. In addition to categories defined in A23's BEP, further detailed and predetermined worksets are included in A04's BEP. Table 4.2. shows predetermined clash detection workset on A04 plot. Electrical workset includes all cable tray installations, lighting fixtures, speakers, and smoke detectors. Mechanical workset consists of HVAC, plumbing, fire protection and gas systems while MEP workset is combination of Electrical and Mechanical worksets.

Table 4.3. Predetermined clash detection worksets in A04.

Zone	Level	Workset 1	Workset 2
ZX	LX	Electrical	Structural
ZX	LX	Electrical	Mechanical
ZX	LX	HVAC	Fire + Plumbing
ZX	LX	Fire Fighting	Plumbing
ZX	LX	Mechanical	Architectural
ZX	LX	Mechanical	Structural
ZX	LX	MEP	Stiffener Columns + Lintels + Smoke
ZX	LX	MEP	Other Disciplines

Clash report requirements are also defined in more detail for A04 compared to A23. For A04, clash reports are required to identify both hard and clearance interferences. Hard interferences refer to situations where geometry of the objects physically overlaps, while clearance interferences indicate predefined clearances between objects are violated. Process of holding regular review meetings plays a crucial role in gaining a full understanding of interferences and finding effective solutions to them. Clash reports must include list of all detected collisions, their status and proposed solutions to these collisions. In BEPs, it is stated that all elements that could potentially have an influence on coordination must be taken into consideration and incorporated in the model, and periodic digital clash detections must be carried out during the construction process until all coordination issues have been resolved, resulting in a clash-free outcome. While more detailed clash report requirement and predetermined work sets on A04 may help with achieving clash-free outcome and may reduce problems in A04, it may also increase time spent on clash detection process. Interviews revealed that coordination between disciplines are weaker in A2A3 plot, in which the level of definition for clash detection is lower compared to A04. A2A3 plot had more clashes and coordination problems occur between different disciplines, specifically between interior design and MEP. Clash detection and coordination issues encountered during the project are explained in detail during “Data Analysis” (Section 4.3) and “Interviews” (Section 4.4) sections.

Non-conformance to Quality Control measures

All BIM models are consistently monitored and checked for their quality to ensure that produced drawings from these models will be accurate at the end. Quality control process is done through meetings between main contractor’s BIM manager, BIM coordinators and authoring stakeholders. While this quality control process is time consuming and provided additional workload for both contractors and project management team, it also reduced the risk of potential errors and rework, made identification and resolve of design issues easier for stakeholders and vastly improved communication between different project participants. Three tiers of quality control processes are identified in project BEPs. BIM authoring leads were responsible from first tier quality control process. If models and drawings proved to be coordinated and compatible with BEP guidelines, they were submitted to the second tier quality control process, which is conducted by BIM coordinators. After that, third tier quality control process is conducted by BIM manager before final approval.

Properly defined family parameters, file, family and element naming, color schemes of the models, zoning and tagging, compliance with modeling guidelines, compliance of model elements with LOD requirements, visual accuracy of the models are checked during this quality control process (Refer to Appendix A). Thus, file, family, and model naming conventions are well-defined and strictly followed for submissions. Accurate naming is also a must to obtain smooth and strong communication and data transfer. Later, data analysis and interview results revealed that non-conformance with quality control measures led to changes in the procedure carried out during the acceptance of drawing packages, resulting in loss of time and labor. Reasons led to the procedure change are explained in detail in "Data Analysis" (Section 4.4) section.

Means of Coordination

Another metric identified in developed framework is "Effective BIM coordination between stakeholders". Also, a study from Abdirad (2016) states that meeting frequency is an important metric that can be used as an evaluation criterion for BIM projects. Higher number and more frequent meetings enhance the coordination and collaboration process. Therefore, projects' BEPs are examined to identify means of coordination and their frequencies. Various types of planned meetings are defined in BEP. Planned meetings and electronic communication is used to achieve coordination. Table 4.5. shows defined meeting types on both project plots. Electronic communication is achieved through three online platforms. These platforms and how they had been used are further detailed in "Technology" (4.2.3.) part.

Table 4.5. Planned meeting types in the project.

Type	Frequency	Participants
BIM Initiation Meeting	One-time	BIM Coordinators, BIM Manager, Site Technical Office Team
BIM Follow Up Meetings	Weekly	BIM Manager of main contractor, Subcontractors
BIM Progress Meetings	Weekly	BIM Manager of project management firm, consultants, main contractor
Design Coordination Meetings	When required	BIM Coordinators, BIM Managers, Consultants and Design Leads/Managers
BIM Workshops for Orientation and Training	When required	BIM Managers, BIM Coordinators, Consultants and Design Leads/Managers
BIM Validation Meetings	Weekly	BIM Coordinators, Subcontractors and Site Technical Office Team

Construction Scheduling and Planning Workflow

"Presence of construction scheduling and sequencing" is another metric identified in developed evaluation framework, which points to the importance of having construction scheduling and sequencing in BIM project to achieve optimal performance. Examination of projects' BEPs revealed that construction scheduling and planning is developed and included in BEPs. 4D Models are created and updated in regular basis with cooperation of Main Contractor's BIM and Design, Planning, Construction, and Logistics teams, to improve communication and data exchange and assist the decision-making process. Figure 4.6. shows scheduling and planning workflow in detail. Effects of revisions and edited BIM models can be seen on the workflow, thus minimizing amount of revision and changes on BIM models are required to achieve best performance. Average number of revisions for disciplines and project plots are analyzed in detail under *Revision and Approved Drawing Information based Analysis* heading in "Data Analysis" (Section 4.3) section.

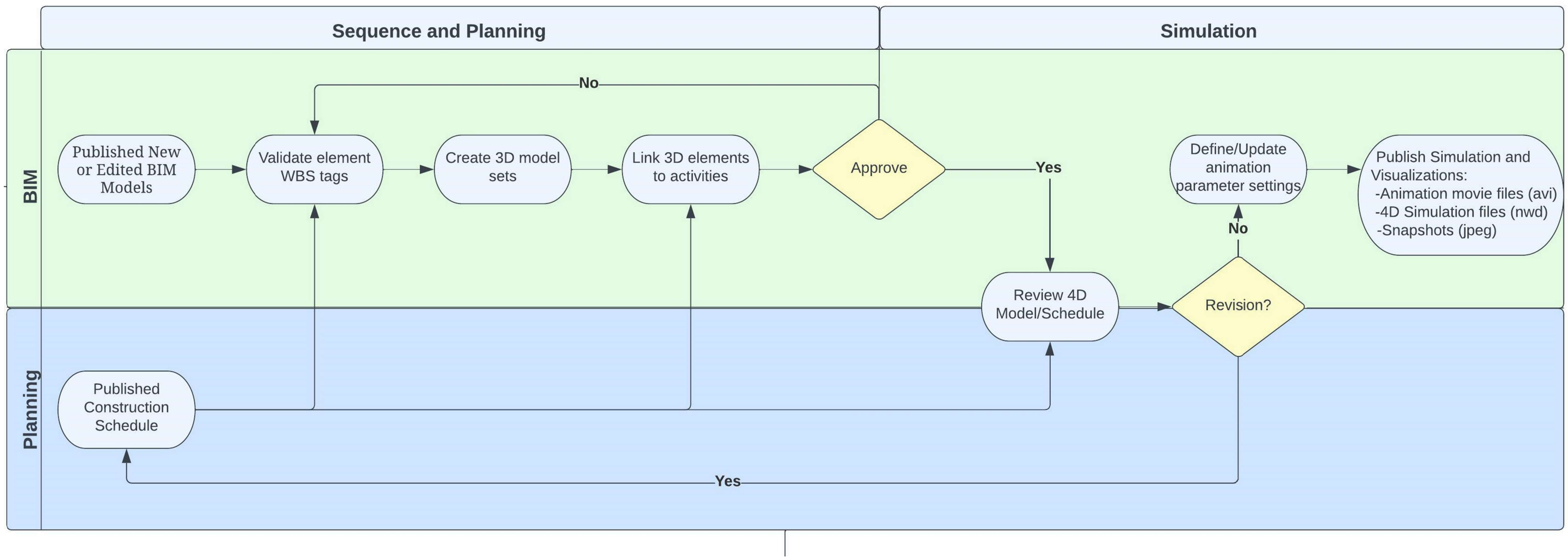


Figure 4.6. Scheduling and Planning workflow of the project. (Source: Project BEP Document)

4.2.1.3. Technology

In this section, software and technological methods used in the project's BIM implementation is explained in detail. Required programs to be used are strictly identified in BEP. Table 4.6. shows identified programs for different project tasks. Revit, Tekla Structure and AutoCAD is identified programs for design development, while Navisworks Manage is identified to be used for clash detection. Synchro 4D Pro is used for construction scheduling and planning. Software versions are specified as well to avoid potential compatibility problems between different stakeholders which can be caused by usage of different program versions.

Table 4.6. Identified programs in BEP for various project tasks.

Software	Used For	Version	File Format
AutoCAD	Design, Modeling and Shop Drawing	2018	dwg
Revit		2018	rvt, rte, rfa, rft
Navisworks Manage/Simulate	Clash Detection	2018	nwc, nwf, nwd
Snychro 4D Pro	Construction Sequencing and Planning	2018	sp, spx

During the "Process" part (4.2.2.) under *Communication* category, it is stated that electronic communication is achieved with help of three platforms during the project. In this section, these platforms are explained in detail. Table 4.7. shows electronic communication platforms used during the project as well as their use purposes.

Table 4.7. Electronic communication platforms

Communication Platform	Used for
Basecamp	BIM related communication and queries, task follow-up
Emropa	BIM model updates and work in progress
Aconex	Formal submittals

Basecamp is mainly used as a platform to distribute to-do lists and tasks and latest information and statements about modeling tasks, as well as a place for Q&A to questions that emerged in coordination and modeling phases. Basecamp is not used for file uploads, but for inquiries and follow-up on tasks. Emropa is used for all file exchanges that are not categorized as formal submission, including informal submissions of models and documents for preliminary reviews and informal swap of documents to be used as reference. Aim of Emropa usage is swift information exchange between project stakeholders with fast model uploads. During the interviews, BIM manager of the project stated that having alternative communication channels used jointly by all stakeholder in addition to the formal communication channels accelerated and enhanced the communication and information exchange process during the project.

ACONEX is used for all formal technical communication during the project. All formal submission including weekly model submissions is done through ACONEX. All model submissions need to contain a revision number at the end of them to indicate current revision number for that model. ACONEX is also the place for submitting official RFI’s in case of need for consultant advice or approvals. These RFI’s along with other issues is reviewed by project stakeholders (main contractor, subcontractors, and lead consultants) in design coordination meetings. Main contractor and subcontractors are responsible to apply resolutions for these RFI’s, which can be delivered in the form of RFI responses or engineering instructions, after these design meetings, before subjected to consultant approval.

All progress files, project BIM models and other content related to project is stored and shared on a private cloud platform owned by the main contractor. Interviews with the main contractor firm revealed that main contractor firm also carried out the technological infrastructure and server installations of the subcontractors and their integration to the cloud system. All files are encrypted and protected with security measures and firewalls to prevent unauthorized person access. Each user received a user account and assigned the appropriate access levels to each directory. The permissions granularity is assigned through an access matrix which is administered by the BIM Coordinators. There are different levels of access types where a user has varying authorization for each file and directory within the project directory tree. Figure 4.7. shows working principles and elements of cloud platform. Presence of both on-site local computer storages and cloud servers ensure rapid sharing of data to mobile devices and off-site 3rd parties while also ensuring redundancy of the data for potential disaster recovery and backup. Interviews with the main contractor firm revealed that, having a strong and unified technological infrastructure and server structure improved data safety, provided reliable storage, enhanced the information flow and exchange processes as well as providing improved communication, therefore affected the BIM performance positively.

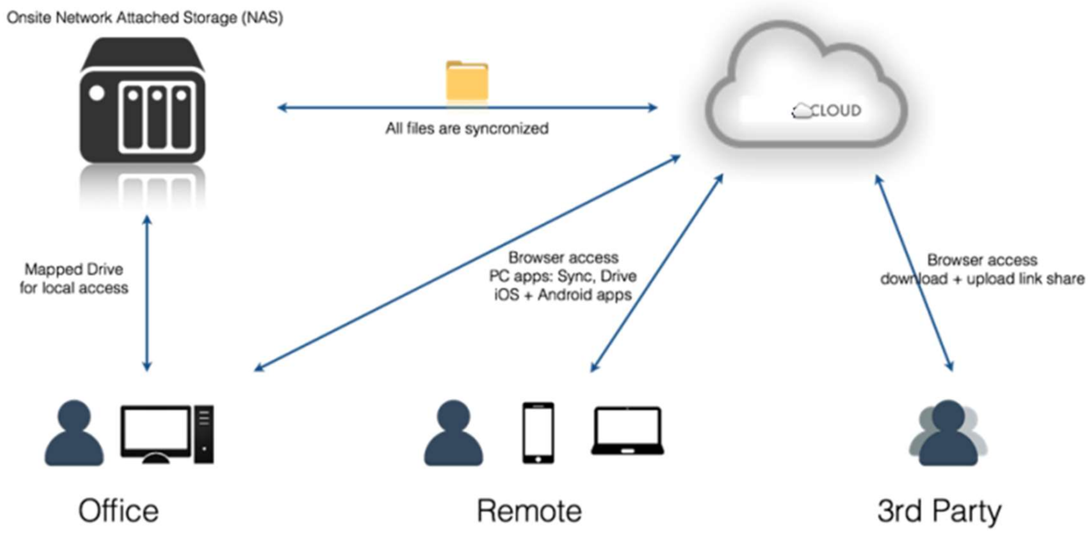


Figure 4.7. Main contractor cloud platform and its working principles.

4.3. Data Analysis

In this part of thesis, collected project data is analyzed to evaluate the BIM performance in project. First, collected data is overviewed to identify and categorize contents, and the issues related with the data are documented. After this overview, data is cleaned and imported into PowerBI analysis software. Imported data is analyzed and evaluated according to the identified criteria from the developed evaluation framework and findings from the section 4.2 BIM implementation.

4.3.1. Data Overview

The analyzed raw data is BIM department's data from the construction phase of the project. The data which was provided by the main contractor firm and consisted of three separate data sets:

- Daily timesheets showing working hours on daily basis for employees in the project team. Each employee has their own Excel file, showing the work done by the employee in detail through the project timeline. There are total of 16 excel sheets under this category.
- ACONEX data for A4 and A2A3 plots exported as Excel files.
- Human resources excel sheet showing individual employee costs and total BIM department cost.

Daily Timesheets

Figure 4.8. shows an example of excel daily timesheet table. Daily timesheet tables contain eleven different data categories. These categories are name, date, discipline, task brief description, and task classification, drawing no, model no, building, floor, hours and remarks. To better understand the contents of these data categories and how the data structured, each of them is explained briefly. "Task brief description" is one of the identified data parameters that can be used for data analysis, but due to the way employees entered the data for this parameter, this parameter could not be used during the analysis. Filtering and analysis based on this parameter could not be done, since employees used many different task brief descriptions for the works that could be defined under the same generalized task brief description. As a result, although they all carry out works that can be described with the same brief description title, the fact that they define these works with different brief descriptions made it impossible to filter and analyze of data based on this parameter. For example, interviews with the main contractor revealed that it is important for main contractor firm to know how much time spent for each task category during creation of shop drawings, like shop drawing updates. Data overview revealed that although it is possible to group them under a more generalized brief description like "shop drawing updates", employees created several different descriptions like "SD-Update", "Shop drawing update", "Shop drawing updates".

BIM MC TIME SHEET											
#	NAME	DATE	DISCIPLINE	TASK BRIEF DESC	TASK CLASSIFICATION	DRAWING NO	MODEL NO	BUILDING	FLOOR	HOURS	REMARKS
1	P16	1-Sep-18	Structural - RC	Annotation- Tag and Dim. of builders work and slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L09-30000	A23-03-XXX-S-RC-L04L15	A03	L09	4.5	Done
2	P16	1-Sep-18	Structural - RC	Annotation- Tag and Dim. of builders work and slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L10-30000	A23-03-XXX-S-RC-L04L15	A03	L10	4.5	Done
3	P16	2-Sep-18	Structural - RC	Annotation- Tag and Dim. of builders work and slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L11-30000	A23-03-XXX-S-RC-L04L15	A03	L11	4.5	Done
4	P16	2-Sep-18	Structural - RC	Annotation- Tag and Dim. of builders work and slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L12-30000	A23-03-XXX-S-RC-L04L15	A03	L12	4.5	Done
5	P16	3-Sep-18	Structural - RC	Annotation- Tag and Dim. of builders work and slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L13-30000	A23-03-XXX-S-RC-L04L15	A03	L13	4	Done
6	P16	3-Sep-18	Structural - RC	Annotation- Tag and Dim. of GA slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L14-30000	A23-03-XXX-S-RC-L04L15	A03	L14	3	Done
7	P16	3-Sep-18	Structural - RC	Annotation- Tag and Dim. of Column setting out	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L14-30002	A23-03-XXX-S-RC-L04L15	A03	L14	2	Done
8	P16	4-Sep-18	Structural - RC	Annotation- Tag and Dim. of Section Details	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L14-30001	A23-03-XXX-S-RC-L04L15	A03	L14	3.5	Done
9	P16	4-Sep-18	Structural - RC	Annotation- Tag and Dim. of Section Details	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L11-30001	A23-03-XXX-S-RC-L04L15	A03	L11	1.5	Done
10	P16	4-Sep-18	Structural - RC	Annotation- Tag and Dim. of Section Details	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L12-30001	A23-03-XXX-S-RC-L04L15	A03	L12	1.5	Done
11	P16	4-Sep-18	Structural - RC	Annotation- Tag and Dim. of Section Details	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L13-30001	A23-03-XXX-S-RC-L04L15	A03	L13	1	Done
12	P16	4-Sep-18	Structural - RC	Annotation- Tag and Dim. of slab	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L15-30000	A23-03-XXX-S-RC-L04L15	A03	L15	1.5	Not Completed
13	P16	5-Sep-18	Structural - RC	Annotation- Tag and Dim. of slab and beam	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L15-30000	A23-03-XXX-S-RC-L04L15	A03	L15	4	Done
14	P16	5-Sep-18	Structural - RC	Annotation- Tag and Dim. Column setting out	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L15-30002	A23-03-XXX-S-RC-L04L15	A03	L15	2.5	Done
15	P16	5-Sep-18	Structural - RC	Details	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L15-30001	A23-03-XXX-S-RC-L04L15	A03	L15	0.5	Done
16	P16	5-Sep-18	Structural - RC	Updating Model Builders work as per new R1 MEP Shop dwg	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L02-10007	A23-03-XXX-S-RC-GFLL03	A03	L02	2	Not Completed
17	P16	6-Sep-18	Structural - RC	File setup, Sheet create, views setup and modele checking as per IFC dwg	MC Scope Shop Drawing	_	A23-03-XXX-S-RC-L16LS2	A03	Multiple	9	L16 to L S2 In progress
18	P16	10-Sep-18	Structural - RC	Sheet create, views setup and modele checking as per IFC dwg	MC Scope Shop Drawing	_	A23-03-XXX-S-RC-L16LS2	A03	Multiple	2	L16 to L S2
19	P16	10-Sep-18	Structural - RC	Annotation- Tag and Dim. of slab and beam	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L16-30000	A23-03-XXX-S-RC-L16LS2	A03	L16	2.5	Incomplete
20	P16	10-Sep-18	Structural - RC	Updating Model Builders work as per new R1 MEP Shop dwg	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L02-10007	A23-03-XXX-S-RC-GFLL03	A03	L02	4.5	Incomplete
21	P16	11-Sep-18	Structural - RC	Updated Model Builders work and Annotation as per new R1 MEP Shop dwg	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L02-10007	A23-03-XXX-S-RC-GFLL03	A03	L02	4.5	Done
22	P16	11-Sep-18	Structural - RC	Updated Model Builders work and Annotation as per new R1 MEP Shop dwg	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L03-10007	A23-03-XXX-S-RC-GFLL03	A03	L03	4.5	Done
23	P16	12-Sep-18	Structural - RC	Annotation- Tag and Dim. Column setting out	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L03-10007	A23-03-XXX-S-RC-GFLL03	A03	L03	1	Done
24	P16	12-Sep-18	Structural - RC	Updated Model Builders work and Annotation as per new R1 MEP Shop dwg	MC Scope Shop Drawing	A23-XXX-SDR-S-GA-L04-30000	A23-03-XXX-S-RC-L04L15	A03	L04	4	Done

Figure 4.8. Example of daily timesheet table. There are 16 daily timesheets with total of 16288 rows of unique entries.

Name section indicates the person who did the work. Main contractor's project team consists of 18 employees. During this thesis, real names of persons will be kept hidden and instead codenames will be used for privacy reasons. Table 4.8 shows names and roles of project team members.

Table 4.8. Project team members working during the project.

EMPLOYEE TABLE

Name	Role	Name	Role
P1	BIM Coordinator	P10	BIM Architect
P2	MEP BIM Coordinator	P11	BIM Engineer
P3	Not defined in tables	P12	Not defined in tables
P4	BIM Engineer	P13	Architectural BIM Coordinator
P5	BIM Engineer	P14	CAD/BIM Operator
P6	Not defined in tables	P15	CAD/BIM Operator
P7	BIM Engineer	P16	CAD/BIM Operator
P8	CAD/BIM Operator	P17	BIM Manager
P9	BIM Engineer	P18	4D BIM Coordinator

Discipline section shows which discipline that the work belongs to. There are total of 10 disciplines under this section. These categories and included tasks for each category are explain briefly below.

- **4D** generally refers to platform and façade coding and coordination works and meetings with subcontractor firm about these works.
- **Architectural – Façade** contains all work about façade including façade coordination, façade model reviews, clash detection and façade model submissions.

- **Architectural – General** refers to general architectural work consists mostly of various layouts and their elevation like finishing layout (FI), block wall (BL), screed layout (SC), tiling layout and elevation (TL), ceiling layout (CE).
- **Architectural – ID** includes all the work about interior design including but not limited to furniture, doors, equipment, creating and updating model families.
- **Architectural – Landscape** contains tasks like surface modelling, drainage, modelling, and coordination of various project elements like landscape lights, swimming pool and MEP plantroom, hardscape modeling.
- **Architectural – Signage** refers to creation and updates about signage model.
- **Logistics** includes modelling and coordination of elements like temporary services and storages, temporary offices, generators, clinic, tower crane and mobile cranes as well as case studies and creations of various plans including traffic management plans, evacuation plans.
- **MEP** discipline include all coordination and modeling works about mechanical, electrical, and plumbing elements in the project like ventilation, third fixes, firefighting, water supply, cable tray, shafts.
- **Structural – RC** refers to all coordination, update and modelling works for reinforced concrete structural elements, like stairs, slab, columns, beams.
- **Structural – Steel** refers to all coordination, update and modelling works for rebars.

Task brief description section contains brief information about the work done, like "updating furniture for bedrooms", "ID-Model fixing", "QA/QC Shop drawings".

Task classification column indicates what category does work done belongs to. Main contractor identified 12 different task classification categories. Tasks are classified under five "Out of Scope" categories, and seven "Main Contractor Scope" (MC) categories. Task classifications also indicate whether the work done belongs to main contractor's scope or not. Because of design changes, management issues, and contractual problems, which are explained in detail in "Interviews" (Section 4.4) and Discussion of the Results (Section 4.5) sections, main contractor had to carry out out of scope tasks that did not belong to the main contractor's scope. Table 4.9. shows task classification categories in daily timesheets. Each out of scope category has different workload for contractor, for some of them, main contractor only did a small portion of work, but for some all work about that task had to be done by the main contractor instead of the appointed subcontractor.

Table 4.9. Tasks are classified as one of the 12 different task classifications. under either “out of scope” or “MC scope” categories.

Task Classification Table

Out of Scope	MC Scope
1) Out of Scope ID	6) MC Scope Complemantary Works
2) Out of Scope Landscape	7) MC Scope Meeting Attendance
3) Out of Scope MEP	8) MC Scope Model & Coordination
4) Out of Scope Signage	9) MC Scope Model Review
5) Out of Scope SC Model vs SD Verification	10) MC Scope Model Submission
	11) MC Scope SC Shop Drawing Review
	12) MC Scope Shop Drawing

“Drawing no”, “Model no”, “Building” and “Floor” columns indicate drawing, model, building names and floor number according to the specified naming schemes in BEP, while “Hours” column shows amount of time spent for that work. “Remarks” column is used to indicate if there is any specific comment or situation about that work.

Aconex Data

The main contractor exported the ACONEX data as excel files for both A4/A1b and A2A3 plots, and later shared these files with the research team. Since exporting as excel files for ACONEX is limited to maximum of 25000 results for a single file, there are total of 13 excel files for A04 and 17 excel files for A2A3 plot. There are total of 316590 entries for A4/A1b plot, and 413291 entries for A2A3 plot. Tables contain 13 main data categories, showing different properties of each result. Figure 4.9. shows part of an excel file that contains an example of the ACONEX data used in analysis.

File	Document No	Title	Revision	Status	Created By	Date Modified	Revision Date	Type	Size	Lock	Discipline
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	00	Submitted For Review	Main Contractor	11.02.2020	08.02.2020	Shop Drawing	542.1 K	No	Structural
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	00	Issued for Comments	Main Contractor	11.02.2020	08.02.2020	Shop Drawing	542.1 K	No	Structural
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	00	Submit to Consultant	Main Contractor	11.02.2020	08.02.2020	Shop Drawing	542.1 K	No	Structural
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	00	Issued For Approval	Main Contractor	12.02.2020	08.02.2020	Shop Drawing	542.1 K	No	Structural
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	00	E - For Information and Record only	Main Contractor	08.03.2020	08.02.2020	Shop Drawing	542.1 K	No	Structural
dwg	A23-MC-SDR-S-GA-RFL-30002_DWG	Plot A03 - Column and Wall General Arrangement Setting Out Plan - Roof/BMU Level	01	Issued For Approval	Main Contractor	21.05.2020	21.05.2020	Shop Drawing	546.4 K	No	Structural

Figure 4.9. Example of ACONEX data table in Excel file format

"File" category indicates the file type used for submission. Both .dwg and .pdf file formats are used for ACONEX drawing submissions. "Document No" column contains the name of the submitted file. Files submitted in dwg format indicated with "_dwg" appendix at the end of the file name. "Title" section shows the content of the drawings in the submitted document. "Revision" row indicates revision number of the submitted document. Interviews with main contractor revealed that revision number is an important indicator for performance, importance of it will be explained in depth in "Interviews" part of this section. Revision numbers are indicated with two digits, ranging from "00" to "07". There are some outliers in revision numbering, for example naming like "REV.00", "Revision", "1", "2", "R0" etc., but these unconventional naming are a negligible portion (less than %0,1) of the total result number. "Revision Date" section represents the date in which the revision of submitted drawing was created, while "Date Modified" column indicates the date for current ACONEX update for that drawing. "Status" column shows the status of the submission. It is possible to understand the reason of issue (approval, review, comment etc.) or current state of the submission (approved, rejected, revise and resubmit etc.), so that one can track the whole process of approval, including intermediate steps, for a submitted drawing rather than only seeing first submission date and final approval date. Table 4.10. shows the status sub-categories for ACONEX data. "Discipline" column indicates which discipline does drawing belong to. This column may help to categorize and analyze submissions according to their disciplines to see if there are any significant differences between revision counts, total submission, or average approval date of drawing submissions between various disciplines. During the data analysis in PowerBI, ACONEX data is analyzed based on average revision numbers and drawing revision distributions for disciplines for each project plot. As mentioned, it is also possible to analyze submission dates and calculate average approval dates of drawings for each revision count and discipline based on ACONEX data, but this analysis is not included in this thesis. Reason for the exclusion of mentioned analysis is based on interviews with the main contractor firm in which BIM manager of the firm stated that “Date modified” and “Revision Date” parameters are manipulated and not reflecting the actual situation in real-life. During the interviews, BIM manager of the main contractor firm stated that due to contractual issues and problems combined with the deliberately late submissions, late checking of the submissions, and unjustified rejections, the suggested analysis based on submission dates would not give accurate results that reflecting the real-life situation. Therefore, although there is sufficient data to carry out such an analysis, average approval analysis is excluded, since analysis made on the available data would not yield correct results due to the reasons stated above. “Type” column is showing the type of the drawing, but not important for data analysis since analyzed ACONEX data is including only shop drawing results. Owner of the drawing can be seen by looking at “Created by” row, while “Size” row shows the submitted drawing size. Status, Discipline and Revision columns contain useful and relevant information that can be used during the analysis when evaluated together with the identified performance indicators according to the literature review and interviews.

Table 4.10. Status Sub-categories for ACONEX data

Status Subcategories		
• A - Approved	• Issued For Action	• No longer in use
• B - Approved with Comments	• Issued For Approval	• Submit to Consultant
• C - Revise and Resubmit	• Issued for Comments	• Submitted for Review
• D - Rejected	• Issued for Contractor Review	• SC to Revise and Resubmit
• E - For Information and Record only	• Issued for Information	
	• Issued for Submission	

Human Resources data

Last data type for the project is human resources table. Figure 4.10. shows the entire human resources table and its contents. This table contains general information and detailed cost for each employee that worked in the project. Three employees that worked in the project (P3, P6 and P12 in Table 4.8.) are not included in human resources table, interviews with the main contractor firm revealed that they were hired as addition to the original team during the project, either because of the additional workload caused by various reasons, or they were sent as employees to the subcontractor firms. This situation and reasons behind it are explained in depth in “Interviews” (Section 4.4) section. “Project”, “Designation”, and “Total” columns are most relevant ones that can be used for analysis within the purpose of this thesis in terms of performing productivity analysis such as relating the cost of an employee to the performed work. “Project” column shows in which part of the project the employee is worked on, A2&A3, A4 or on both, which indicated as “common”. “Designation” column points out employee’s role in the project, while “Total” column represents total cost of an employee, including but not limited to yearly gross salary, notice payment and indemnity payments.

Project	Name Surname	Designation	Years Worked	Yearly Gross Salary	Flight Ticket Allowance (Yearly)	Visa Cost (Yearly)	Insurance Cost (Yearly)	Indemnity Payment	Annual Leave Payment	Notice Payment	Total
A2&A3	P14	CAD/BIM OPERATOR	1,4	148.200,00	2.000,00	1.750,00	2.769,47	7.672,02	1.052,05	-	163.443,54
A4	P16	CAD/BIM OPERATOR	1,5	174.000,00	2.000,00	1.750,00	2.769,47	9.618,47	4.734,25	-	194.872,19
A4	P7	BIM ENGINEER	1,9	171.000,00	3.000,00	1.750,00	2.769,47	4.152,55	2.128,77	-	184.800,79
A4	P5	BIM ENGINEER	2,1	162.000,00	3.000,00	1.750,00	2.769,47	11.994,24	-	13.315,07	194.828,78
A2&A3	P4	BIM ENGINEER	2,1	216.000,00	3.250,00	1.750,00	2.769,47	17.001,13	-	17.753,42	258.524,02
COMMON	P8	CAD/BIM OPERATOR	2,5	148.200,00	2.000,00	1.750,00	4.611,00	13.573,67	8.942,47	-	179.077,14
A2&A3	P11	BIM ENGINEER	5,2	158.400,00	5.000,00	1.750,00	7.418,00	33.098,87	9.073,97	13.019,18	227.760,02
COMMON	BIM MANAGER	BIM MANAGER	5,2	527.280,00	5.000,00	1.750,00	7.418,00	105.359,51	29.036,71	43.338,08	719.182,31
COMMON	P10	BIM ARCHITECT	5,2	174.151,92	5.000,00	1.750,00	7.418,00	34.214,99	9.464,55	14.313,86	246.313,31
A2&A3	P2	MEP BIM COORDINATOR	5,2	312.000,00	2.000,00	1.750,00	15.423,00	58.675,47	16.273,97	25.643,84	431.766,28
COMMON	P13	ARCHITECTURAL BIM COORDINATOR	5,0	306.000,00	2.000,00	1.750,00	4.611,00	55.626,32	15.780,82	25.150,68	410.918,82
A2&A3	P15	CAD/BIM OPERATOR	5,0	148.200,00	2.000,00	1.750,00	4.611,00	27.646,70	7.890,41	12.180,82	204.278,94
A2&A3	P9	BIM ENGINEER	4,6	144.000,00	3.250,00	1.750,00	4.611,00	23.946,86	7.397,26	11.835,62	196.790,73
COMMON	P1	BIM COORDINATOR	4,3	204.000,00	2.000,00	1.750,00	4.611,00	28.212,27	9.369,86	16.767,12	266.710,26

Figure 4.10. Human resources table for A2A3 and A04 plots.

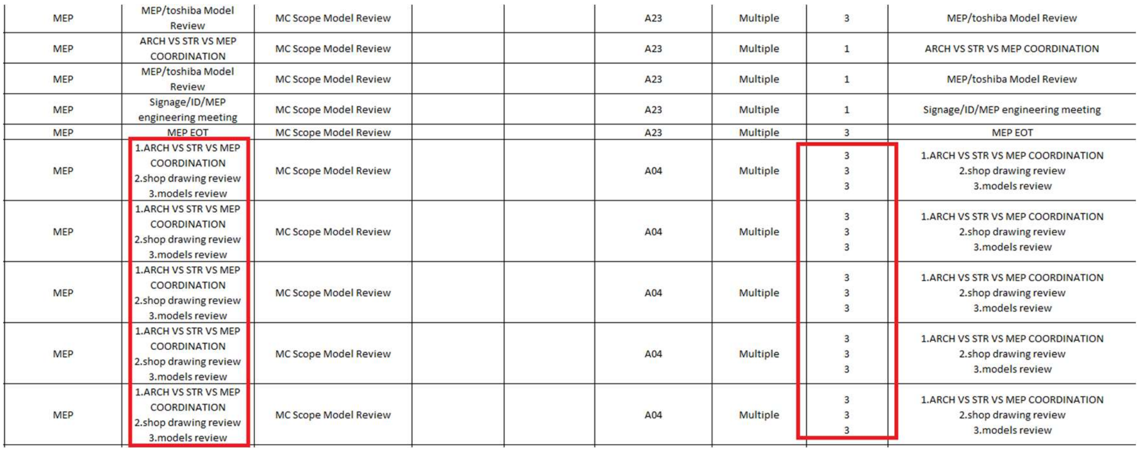
4.1.1. Data Quality and Problems in Dataset

During the initial data overview and while importing the dataset to PowerBI, a number of issues with the dataset were identified. In this section, these issues are briefly discussed to evaluate the reasons for such issues, why they are important for analyses and how the data should have been entered and gathered to avoid these issues for future research.

Identified data issues can be grouped in two main categories and have the potential of affecting analyses results. First category includes issues that are related to the way that the data is entered into excel files (non-standard data entry). Since there were no missing data, issues related to this category were corrected before conducting the analyses. On the other hand, there were also issues related to missing data within the dataset (non-available data entry). The missing data was mainly as a result of the person entering the data not filling all the necessary categories. Therefore, issues that belong to the second category could not be corrected before conducting analyses.

Issues Related with Non-standard Data Entry

One of the issues that was spotted during the data overview and analyses was about the way that manhour information entered in "Hours" column of the dataset (Figure 4.11.). One employee divided the work he/she had done into smaller tasks under brief task description column but instead of creating separate entries for each of these tasks, they entered the tasks one below the other in the same entry for both task description and hour column. During the analyses, PowerBI was unable to read hour data for these entries and showing errors in "Hours" column, since the data entry method was not compatible with excel's entry type for number data. If the issue was not noticed by the researchers this might have led to a portion of the time spent not being included in the analyses. Therefore, before conducting the analyses, problematic entries were spotted by using "Show errors" feature in PowerBI and were corrected afterwards. There were total of 317 entries with this specific data entry problem corresponding to a total of 2844 hours of work. This means that if this problem, which was caused by employee's wrong data entry style, was not identified and corrected during the analyses, %5.19 of total project time would not have been reflected in the analyses.



MEP	MEP/toshiba Model Review	MC Scope Model Review			A23	Multiple	3	MEP/toshiba Model Review
MEP	ARCH VS STR VS MEP COORDINATION	MC Scope Model Review			A23	Multiple	1	ARCH VS STR VS MEP COORDINATION
MEP	MEP/toshiba Model Review	MC Scope Model Review			A23	Multiple	1	MEP/toshiba Model Review
MEP	Signage/ID/MEP engineering meeting	MC Scope Model Review			A23	Multiple	1	Signage/ID/MEP engineering meeting
MEP	MEP EOT	MC Scope Model Review			A23	Multiple	3	MEP EOT
MEP	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review	MC Scope Model Review			A04	Multiple	3 3 3	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review
MEP	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review	MC Scope Model Review			A04	Multiple	3 3 3	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review
MEP	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review	MC Scope Model Review			A04	Multiple	3 3 3	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review
MEP	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review	MC Scope Model Review			A04	Multiple	3 3 3	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review
MEP	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review	MC Scope Model Review			A04	Multiple	3 3 3	1.ARCH VS STR VS MEP COORDINATION 2.shop drawing review 3.models review

Figure 4.11. Each data should be entered in separate rows in the marked cells. However, the data in the marked cells is entered in single cells as if they were separate cells. This resulted in PowerBI not being able to read the data in such cells.

Second data entry issue is about the errors done by employees while entering the drawing names. Some of the works performed were related with multiple drawings, and instead of writing them down in single entry, several employees entered each of these drawings as separate entries (Figure 4.12.). This would not be a problem if the information in other columns (hours, discipline, task classification etc.) was also entered individually for each drawing. Since these employees did not think them as separate entries, they only entered drawing names. This resulted in entries consisting of only drawing name, and data in other columns for these entries were identified as “Blank”. Since there were no analyses related to the drawing names, this did not affect the analyses results for this research, but this problem related with the data entry method should be taken into consideration future research that intends to perform analyses based on individual drawing name or type.

Architectural - General	Annotation& Tag,Dimensions etc	MC Scope Shop Drawing	A23-TAV-SDR-A-BW-GFL-20001 A23-TAV-SDR-A-BW-GFL-20002 A23-TAV-SDR-A-BW-GFL-20003 A23-TAV-SDR-A-BW-GFL-20004 A23-TAV-SDR-A-BW-GFL-20005 A23-TAV-SDR-A-BW-GFL-20006 A23-TAV-SDR-A-BW-GFL-20007 A23-TAV-SDR-A-BW-GFL-20008	A23-23-TAV-A-FN-GFLL03-EX	A23	B01	0,5
Architectural - General	Annotation& Tag,Dimensions etc	MC Scope Shop Drawing	A23-TAV-SDR-A-SC-B02-10001	A23-23-TAV-A-FN-GFLL03-EX	A03	B02	4
Architectural - General	Annotation& Tag,Dimensions etc	MC Scope Shop Drawing	A23-TAV-SDR-A-BW-GFL-30001 A123-TAV-SDR-A-BW-GFL-30002	A23-23-TAV-A-FN-GFLL03-EX	A03	B02	1,5
			A23-TAV-SDR-A-BW-GFL-30002				
			A23-TAV-SDR-A-BW-GFL-30003				
			A23-TAV-SDR-A-BW-GFL-30004				
			A23-TAV-SDR-A-BW-GFL-30005				
			A23-TAV-SDR-A-BW-GFL-30006				
			A23-TAV-SDR-A-BW-GFL-30007				
			A23-TAV-SDR-A-BW-GFL-30008				
			A23-TAV-SDR-A-BW-L01-20001				
			A23-TAV-SDR-A-BW-L01-20002				
			A23-TAV-SDR-A-BW-L01-20003				
			A23-TAV-SDR-A-BW-L01-20004				
			A23-TAV-SDR-A-BW-L01-20005				
			A23-TAV-SDR-A-BW-L01-20006				
			A23-TAV-SDR-A-BW-L01-30001				
			A23-TAV-SDR-A-BW-L01-30002				
			A23-TAV-SDR-A-BW-L01-30003				
			A23-TAV-SDR-A-BW-L01-30004				
			A23-TAV-SDR-A-BW-L01-30005				
			A23-TAV-SDR-A-BW-L01-30006				
			A23-TAV-SDR-A-BW-L01-30007				
			A23-TAV-SDR-A-BW-L01-30008				
Architectural - General	Annotation&	MC Scope Shop Drawing	[illegible]	A23-23-TAV-A-FN-B06B01-EX	A02	B02	2

Figure 4.12. Entering data that should be entered in single cell in separate cells causes inaccurate results in analysis.

Issues Related with Non-available Data

First two problems that were mentioned in the Data Overview (4.3.1.) section were caused by user errors. Employees entered data in non-standard ways, but since there was no missing information, these problems could be fixed later by the researchers. However, there were also issues that were due to missing data within the dataset. Some employees did not enter into the project database data related to drawing name, model name, building and floor information about the work they had performed (Figure 4.13.). This situation led to challenges in data analysis, especially for building based total time spent analyses. These problematic entries caused “Blank” result to appear in building based total time spent and time spent for each discipline analyses. Since these results corresponded to %0.45 of total time spent and had no meaningful impact on any of these analyses, they were neglected and excluded from the results. However, just because this specific problem did not affect the results in this research, does not mean that they can be neglected in general. Thus, these identified issues and errors should be taken into account while entering data in project database and collecting this type of data for further research.

893	P14	24-Aug-19	Structural - RC	Core Wall Key Plan (Checking Beam & Plan View)	MC Scope Shop Drawing	NA	A23-03-TAV-S-RC-L53RFL-EX	A03	L63	8	Not Completed
894	P14	25-Aug-19	Structural - RC	Core Wall Key Plan (Checking Beam & Plan View)	MC Scope Shop Drawing	NA	A23-03-TAV-S-RC-L53RFL-EX	A03	L63	8	Completed
895	P14	25-Aug-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L53-30111 A23-TAV-SDR-S-GA-L54-30111 A23-TAV-SDR-S-GA-L55-30111 A23-TAV-SDR-S-GA-L56-30111 A23-TAV-SDR-S-GA-L53-30112 A23-TAV-SDR-S-GA-L53-30113 A23-TAV-SDR-S-GA-L53-30114 A23-TAV-SDR-S-GA-L53-30115	A23-03-TAV-S-RC-L53RFL-EX	A03	Multiple	8	(Engineering Comments Updated send back to them) Completed
896	P14	26-Aug-19	Structural - RC	GA Slab drawings	MC Scope Shop Drawing	NA	A23-23-TAV-S-RC-B06B01-EX A23-23-TAV-S-RC-GFLL03-EX	A01	Multiple	8	Ramp Clarification for GRD & B01
897	P14	26-Aug-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L63-30111 A23-TAV-SDR-S-GA-L63-30112	A23-03-TAV-S-RC-L53RFL-EX	A03	L63	8	Not Completed
898	P14	27-Aug-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L63-30111 A23-TAV-SDR-S-GA-L63-30112	A23-03-TAV-S-RC-L53RFL-EX	A03	L63	8	Completed
899	P14	28-Aug-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L63-30111 A23-TAV-SDR-S-GA-L63-30112	A23-03-TAV-S-RC-L53RFL-EX	A03	L63	8	
900	P14	29-Aug-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing					8	
901	P14	1-Sep-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing					8	
902	P14	2-Sep-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing					8	
903	P14	3-Sep-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing					8	
904	P14	4-Sep-19	Structural - RC	Core Wall Key Plan Core Wall Sectional Details	MC Scope Shop Drawing		-			8	
905	P14	5-Sep-19	Structural - RC	Core Wall Key Plan Core Wall Sectional	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L64-30111 A23-TAV-SDR-S-GA-L65-30111	3	A03	Multiple	8	Completed

Figure 4.13. Entries with missing building information led to inaccurate building based time analysis results.

Missing model names within the dataset is important not only for the performance analyses done after the project is completed, but also for the main contractor in terms of project management during the project. Its importance to main contractor firm can be seen in entries in which the BIM manager of the project realized the issue and specifically commented on the “Model name” column about the need for entering model names (Figure 4.14.).

Structural - RC	Updating shop drawings	MC Scope Shop Drawing		BIM MANAGER: INDICATE THE MODEL NO	A02	Multiple	5
Structural - RC	Updating shop drawings	MC Scope Shop Drawing		BIM MANAGER: INDICATE THE MODEL NO	A02	Multiple	5
Structural - RC	Updating shop drawings	MC Scope Shop Drawing		BIM MANAGER: INDICATE THE MODEL NO	A02	Multiple	4,5
Structural - RC	Updating shop drawings	MC Scope Shop Drawing		BIM MANAGER: INDICATE THE MODEL NO	A02	Multiple	4
Structural - RC	Updating shop drawings	MC Scope Shop Drawing		BIM MANAGER: INDICATE THE MODEL NO	A02	Multiple	4
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-B01-10004	A23-23-TAV-S-RC-B06B01-EX	A02	B01	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-B01-10005	A23-23-TAV-S-RC-B06B01-EX	A02	B01	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-B01-10011	A23-23-TAV-S-RC-B06B01-EX	A02	B01	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L04-30000	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L04-30001	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L04-30002	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L05-30000	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L05-30001	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-L05-30002	A23-03-TAV-S-RC-L04L15-EX	A03	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-21000	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-21001	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-21002	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-22000	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-22001	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6
Structural - RC	Updating shop drawings	MC Scope Shop Drawing	A23-TAV-SDR-S-GA-GRD-22002	A23-23-TAV-S-RC-GFLL03-EX	A02	Multiple	0,6

Figure 4.14. Employees that were not entering model names were specifically reminded by the BIM manager to enter model names to improve the quality of the project database.

4.3.2. Data Analysis in PowerBI

In this part, imported project data is analyzed under three main categories to evaluate the BIM performance in the project: (1) discipline based performance analysis, (2) task classification based performance analysis, and (3) revision and approved drawing information based performance analysis.

Discipline Based Performance Analysis

Project data is filtered according to hours spent for each discipline to evaluate the ratio between different disciplines, and to identify whether any discipline(s) stick out in terms of higher total time spent compared to others (Figure 4.15.) Conducted analysis revealed that "Architectural-General" has the highest time ratio with %43.24 of total time, followed by "Structural-RC" with %24.94 and "MEP" with %16.89.

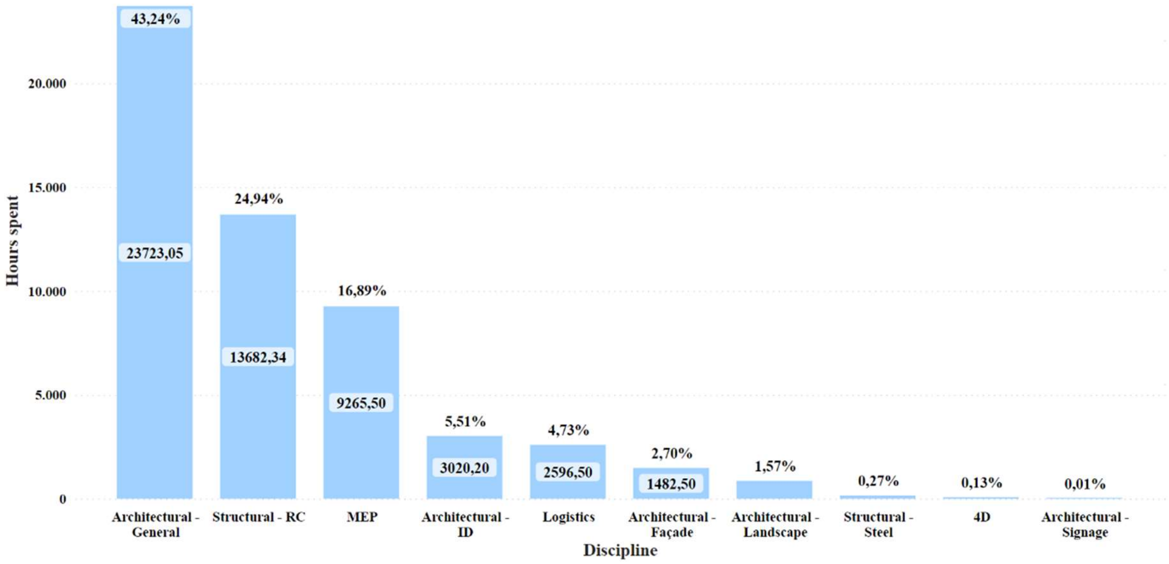


Figure 4.15. Hours spent per discipline by BIM department for overall project.

Further investigation is done for the ratios of different disciplines by filtering the data according to both disciplines and the two project plots, rather than filtering the data only by discipline. Figure 4.16. shows time spent for each discipline based on project plots. For this chart, Structural-Steel and Structural-RC disciplines combined into a single discipline and named as “Structural”, since Structural-Steel corresponds into only %0.27 of total time spent and for A2A3 and A4 plots, difference between time spent for that discipline is negligible with only 20 hours between them. Main reason for this filtering is to see if there are any meaningful differences between discipline-based ratios for different project plots. In “General overview of the project” part of this chapter, it is indicated that A2A3 plot has a significantly higher development area (213110 square meters) with two towers (A2 and A3) compared to A4 plot’s development area (134163 square meters) with one tower (A4). The A2A3 and A4 towers’ characteristics are similar, however A2A3 has more development area and includes two towers rather than one we assumed that the data for the A2A3 plot would indicate more time spent for each discipline when compared to A4 plot data. While the data from most of the disciplines are in parallel with our assumption, MEP discipline has significantly higher time spent on A04 plot rather than the A2A3 plot, which is the opposite of what we anticipated. Logistic department is another department which shows higher time spent on A04 plot compared to A2A3 plot, but difference between two project plots for logistics discipline is not as significant as in MEP discipline.

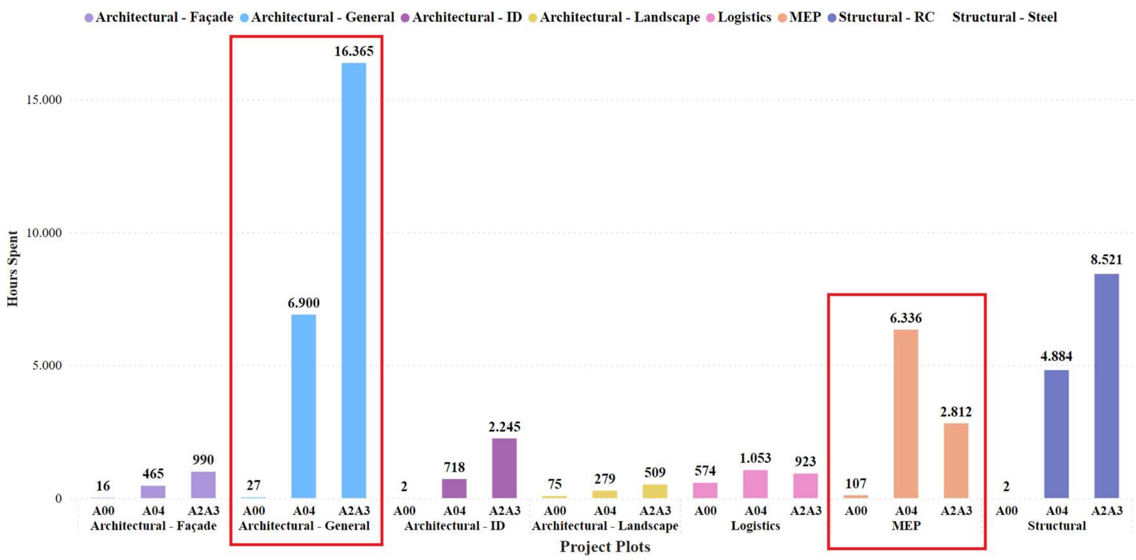


Figure 4.16. Hours spent per discipline based on project plots. Based on project properties, it is expected that A2A3 plot would have higher time spent for every discipline, but MEP results showed the opposite. Also, the difference between project plots based on Architectural-General discipline is significantly higher compared to other disciplines.

Plot-based percentage distributions of time spent for each discipline are also investigated to see if there are any significant differences for percentage ratios between disciplines for different plots (Figure 4.17.). Results shows that MEP discipline had significantly higher percentage on A04 plot (%30,71) compared to A2A3 plot (%8,69). This may indicate that there were problems that led to higher amount of time spent for MEP, thus reducing the overall performance, but there are more factors to consider before coming into this conclusion. During the investigation of BEP, we observed that coordination and clash detection requirements, especially those are related with MEP part, is far more detailed on A04 plot. This situation brings out another possibility, in which the reason for the higher amount of time and percentage for MEP discipline in A04 may be the result of the better defined coordination process that took more time compared to A2A3, at the same time contributing to a better performance with less changes in on-site construction, thanks to clash-free models. Thus, by looking at these two graphs only, one cannot arrive at a certain conclusion about the time spent on MEP on different plots as a definitive performance indicator of MEP performance on each plot, additional analysis and interviews are needed.

	A2A3	A04
Architectural - General	50,57%	33,44%
Structural	26,33%	23,67%
MEP	8,69%	30,71%
Architectural - ID	6,94%	3,48%
Architectural - Façade	3,06%	2,25%
Logistics	2,85%	5,10%
Architectural - Landscape	1,57%	1,35%

Figure 4.17. Percentage distribution of time spent for each discipline for both plots. Results indicating significantly higher ratio for MEP discipline on A04 plot compared to A2A3 plot.

The dataset has exact date data alongside with hours spent for each entry. Detailed analysis of time graph for hours spent per discipline is done to reveals information about disciplines' performances to indicate potentially problematic time slots along the project's timeline. Below is the graph showing time spent for MEP discipline for each project plot for each month (Figure 4.18,). For MEP discipline, while A04 plot has more stable and continuous time graph with minimal disconnections, A2A3 shows clearly more disconnected and uneven distribution. This situation supports the possibility of performance problems in MEP discipline for A2A3 plot.

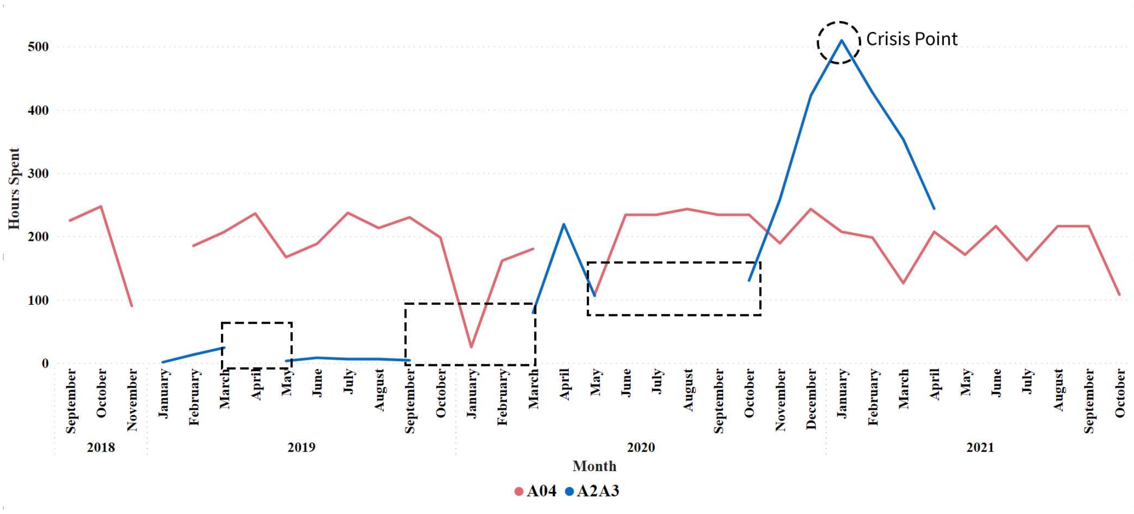


Figure 4.18. Time graph of hours spent for MEP for each project plot. Other disciplines on A2A3 plot show continuous graphs, while big gaps and discontinuation of the graph (dotted black rectangles) for MEP discipline indicate potential problems.

For every discipline-based time graph (other than MEP), A2A3 shows significantly higher amount of time spent in a continuous line without disconnections (Figure 4.19.). Another notable issue that can be seen in these graphs is disconnection between March 2020 and June 2020 for A04. Graphs show that almost no work was done on the A04 during this period. Interviews with the main contractor revealed that this situation is not indicating a performance problem related to the A04 project but related with project owner's decision to stop the works for A04 mainly due to COVID-19.

Figure 4.19. Time graph of time spent for "Architectural" and "Structural disciplines. Shaded area between dotted lines shows the time period that no work was done on A04 plot. Interviews revealed that this situation resulted from the owner's decision, not from problems on the project.

When looking at the overall graph for MEP (Figure 4.18), nearly all the MEP time for A2A3 plot is spent in two time periods, which are March 2020-May 2020 and October 2020-April 2021, instead of the more homogenous spread of A04 MEP time. Only 65 hours is spent for A2A3's MEP discipline outside of these periods. %14.3 of MEP time for A2A3 is spent in March 2020-May 2020 and this time period shows a similar pattern compared to A04. %84.8 of MEP time for A2A3 is spent between October 2020-April 2021, with a peak of 509 hours for January 2021. During the interviews, these peaks are named as "crisis points" by BIM manager of the main contractor firm. BIM manager stated that these "crisis points" show the periods when the works that are approaching or exceeding the deadlines accumulate and after the project owner's request for acceleration, these works are tried to be completed quickly with an intense pace and which can lead to problems such as poor quality. Overall, the time graph of hours spent for MEP discipline and the discipline-based percentage graphs for each plot indicate a performance problem for MEP discipline in project. Meanwhile the amount of time spent for A2A3 plot seems suspiciously low. However, these analyses are not adequate to draw any firm conclusions. This is due to potential problems within the dataset, such as data entered incorrectly by the employees (such as wrong discipline) or not entered at all. Less amount of time for MEP discipline on A2A3 plot may be attributed to issues with information flow (such as inadequate information about design, late arrival of information) from MEP subcontractor which can be caused by lack of coordination, incompetency of subcontractor, or contractual problems. Another possibility for this difference is presence of different design teams for each plot. Internal structure of design team in A2A3, their design process and collaboration and communication issues may have caused problems and delays in MEP part of the project. Further analysis such as time spent for each task classification and interviews are carried out to better understand and evaluate the reasons (refer to "Interviews" (Section 4.4) for more information).

Task Classification Based Performance Analysis

Collaboration and coordination between project stakeholders and coordination of BIM models are important metrics for the assessment (Abdirad, 2016; ENR, 2020). Importance of coordination and collaboration can also be seen in BEPs of the project plots. Both A2A3's and A04's BEP have separate sections for coordination, communication and clash detection supported with hybrid cloud file sync and model and file sharing platform. Quick interviews with project staff revealed that it is important for the main contractor company to understand the ratio between time spent on actual shop drawing creation, and other works such as model review, modeling and coordination, and complementary works, as their main responsibility in the project was creating shop drawings. Thus, time spent for each task classification for overall project is analyzed to understand the ratio between actual shop drawing creation and other works. Figure 4.20. shows time spent for each task classification for overall project. According to the data, %42.40 of main contractor's total time is spent for actual shop drawings, while %46.91 of total time is spent on other in-scope tasks (MC Scope Model & Coordination, MC

Scope Model Review, MC Scope Complementary Works, MC Scope Model Submission and MC Scope Meeting Attendance) required to be done before or during producing final shop drawings. Results show there are also "out of scope" categories among the task classifications in the project data. Project participants' roles and the scope of their work are predefined and stated in BEP and other legal documents. Out of scope task refer to work that is not in the scope of the main contractor. However, due to a number of reasons, including but not limited to technical problems, incompetency of subs, and time constraints out of scope tasks are taken over by the main contractor. Analysis indicates that %9,23 of the main contractor's total time was spent on the out of scope tasks.

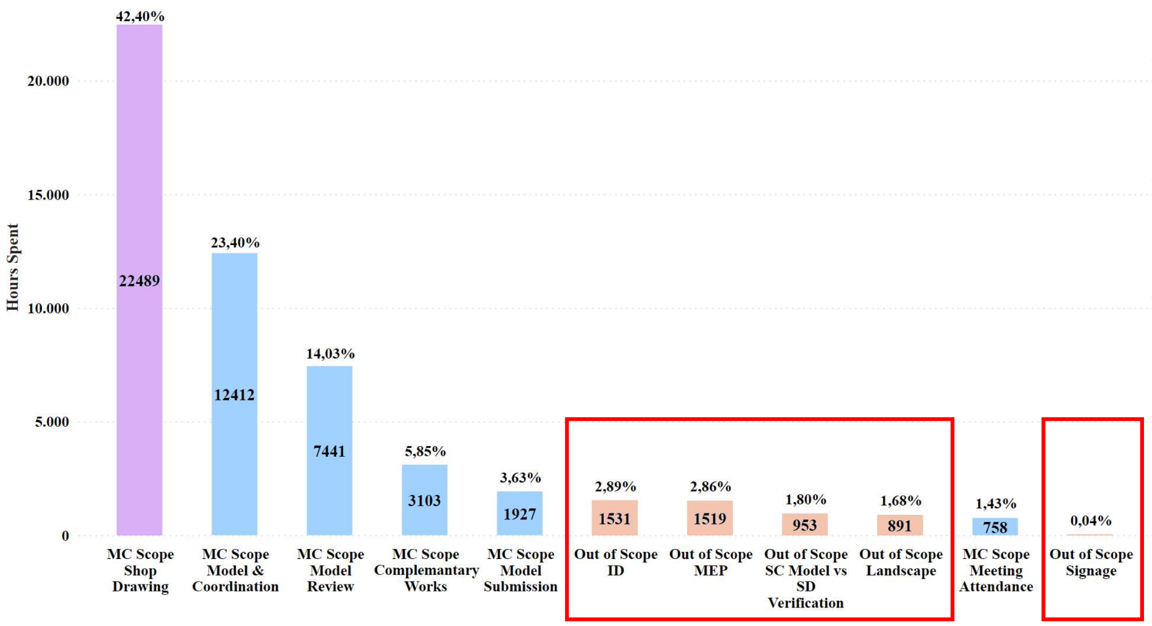


Figure 4.20. Time spent for each task classification for overall project. Results show that %42,40 of main contractor's time was spent on actual creation of shop drawings, while %46,91 of their time was spent on other in-scope tasks. Remaining %9,23 spent on out of scope tasks (indicated with red rectangles).

In next step, time spent for each task classification is analyzed for each project plot specifically (Figure 4.21.). As mentioned earlier, considering the characteristic properties such as sizes of two project plots, it is expected that A2A3 plot has higher time spent on each task classification category. Most of the task classifications support this assumption except MC Scope Model Review. Significantly higher time was spent on MC

Scope Model Review task classification for the A04 plot compared to the A2A3 plot. While on A2A3 plot, %5.81 of total time is spent for MC Scope Model Review, this ratio increases to %26.92 of total time on A04 plot. Other task classifications show significantly less variance, with highest variance of %4.79 for MC Scope Model & Coordination. This may indicate problems in A04, possibly related with quality control, that required significant amount of time spent for reviewing and controlling models, thus impacted performance negatively. Results for "Out of scope MEP" task classification (Figure 4.21.) helped us gain better understanding of MEP discipline performance on A2A3 and A04 plots. In the discipline-based time spent analysis (Figure 4.16, p.56), for every discipline except for MEP, A2A3 plot has significantly higher time spent compared to A04. Such result was anticipated since A2A3 plot has significantly higher development area and consisted of two towers rather than the single tower on the A04 plot. MEP discipline has significantly higher time spent on A04 plot compared to A2A3 plot, and A2A3's time graph for MEP discipline shows different and incompatible pattern compared to other disciplines' time graphs. Moving on to task classification analysis, results show that 1519 hours is spent for out of scope MEP tasks in A2A3 plot, while A04 plot has none. This situation further supports the assumption that A2A3 plot has performance problems related with the MEP discipline. Another outcome that is obtained from the analysis of the out of scope MEP task classification is that it is the only out of scope classification that has no time spent for A04 plot, all out of scope tasks except MEP shows time spent for both A2A3 and A04 plots. This means that while overall MEP time spent for A04 is significantly higher than A2A3, all the work that is done on A04 plot is within the main contractor's scope, there were no problems that forced main contractor to extend their work outside of their contractual responsibilities. Results also indicate the existence of problems that caused out of scope tasks on Architectural-Landscape and Architectural-ID disciplines. Detailed analyses are conducted about the ratios for out of scope and in scope tasks for each plot and each discipline.

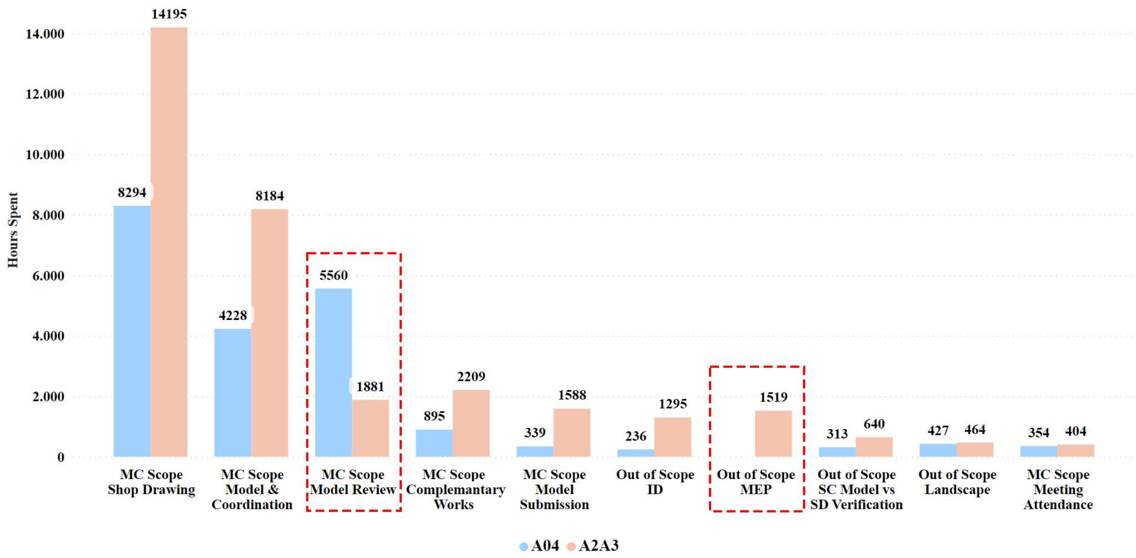


Figure 4.21. Time spent for each task classification for each project plot. Out of scope MEP results support the assumption of problems in the A2A3 plot. MC Scope Model review classification shows significantly higher time spent on A04 compared to A2A3, which is the opposite results than expected given the project characteristics.

Further detailed analysis about task classifications revealed the ratio between time spent for out of scope tasks and MC scope tasks both for overall project and individual project plots (Figure 4.22.) to evaluate whether the out of scope tasks effected on the main contractor's project performance. For this analysis, task classifications are categorized under two main categories, as "Out of Scope tasks" and "MC Scope Tasks", according to the task classification table (Table 4.9) in page 51, "Data Overview" part of this chapter. Analysis results indicate that %9.23 of overall project time is spent for out of scope tasks. Moving on to plot specific results, out of scope tasks took 976 hours in A04 plot, which corresponds to %4.64 of total time spent for that plot. In A2A3 plot, this ratio increases to %12,13 with total of 4030 hours spent for out of scope tasks. These results support the previous assumption that, compared to A04, A2A3 plot has more problems that affected performance negatively, and significantly more time is spent for out of scope tasks in A2A3. The amount of time spent on the A2A3 plot's out of scope tasks may be related with things such as: (a) the presence of different designer teams for each plot, (b) subcontractors, and designer team on A2A3 may be less competent when compared to A04, or (c) simply design of the A2A3 may be problematic. The problematic design might have led to conflicts and significant amount of rework, in which the main contractor firm ended up intervening the situation and take over tasks that were not in their scope. The assumptions are discussed during the interviews with main contractor in order to pinpoint the real reasoning for the out of scope task percentages for both plots in “Interviews” (Section 4.4) section.

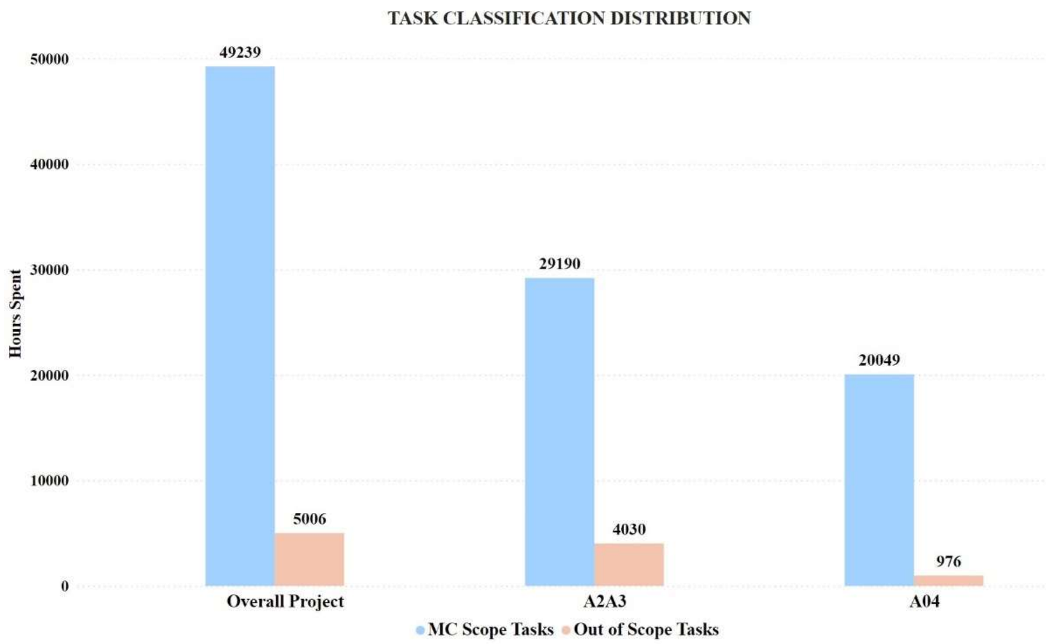


Figure 4.22. Out of Scope and MC Scope task time ratios for individual project plots and overall project. Results for A04 plot shows significantly lower out of scope task ratio compared to A2A3 plot.

Further investigation of the out of scope and in scope task ratios for MEP discipline on A2A3 plot would provide additional information about the performance, thus as the next step, time spent for MEP discipline in A2A3 plot is filtered according to task classifications (Figure 4.23.). This analysis revealed that %56.69 of tasks for MEP discipline are out of scope tasks. Earlier in this chapter, it is indicated that %84.8 of MEP time for A2A3 is spent between October 2020 and April 2021. Time graph shows that, in that time period, after January 2021, in scope task time is showing a continuous sharp decrease and out of scope tasks ratio to total MEP time is increasing dramatically. These results again support the interpretation of data regarding the performance problem claims about A2A3. Reduced amount of work and discontinuous pattern may be the result of problems related with the contract, the design, or subcontractors’ incompetency. For some reason, main contractor may have had to intervene and undertake subcontractors' tasks, which may explain the high ratio and amount of out of scope time.

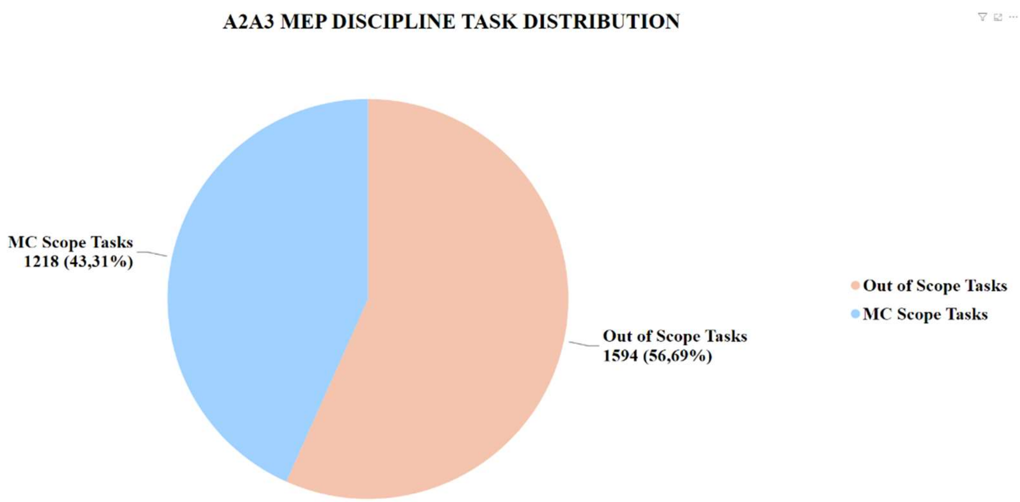
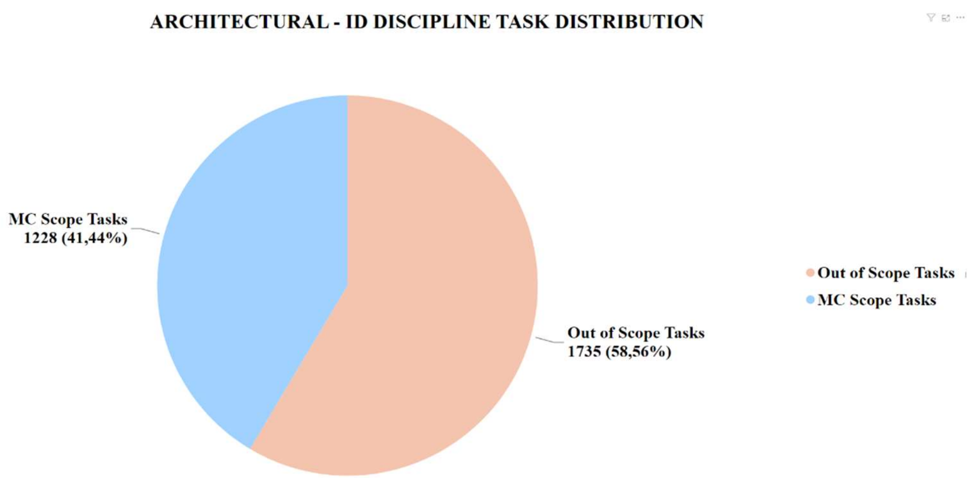


Figure 4.23. Time spent for MEP discipline in A2A3 according to task classification. Analysis for the MEP discipline indicates that more than half of the time is spent on the out-of-scope category tasks on the A2A3 plot.

Results from task classification analysis points out two more problematic disciplines with out-of-scope tasks besides the MEP discipline. These disciplines are Architectural–ID and Architectural–Landscape. Investigation of overall project graphs reveals that more than half of the total time is spent on out of scope tasks for both disciplines: %58.52 for Architectural–ID and %54 for Architectural–Landscape (Figure 4.24.). Plot specific results also support the assumption of performance problems for these disciplines. For the Architectural-ID discipline, %55.31 of total time is spent on out of scope tasks on A2A3 plot and %68.57 of total time is spent on out of scope tasks on A04 plot. For Architectural-Landscape discipline, out of scope task ratios are %40.24 on A2A3 and %82.8 on A04 plots. Both plots show close results for time spent on out of scope tasks for Architectural-Landscape: 235 hours for A2A3 plot, and 231 hours for A04 plot. Meanwhile investigation of data on the MC Scope tasks results show completely different story. On A04 plot only 48 hours were spent on Architectural-Landscape discipline related tasks that are in the main contractor's scope, while on A2A3 plot, this number rises to 349 hours. This suggests that Architectural-Landscape discipline have bigger performance problems on A04 plot compared to A2A3 plot, since the MC spent significantly more time on out of scope tasks for the A2A3 plot.



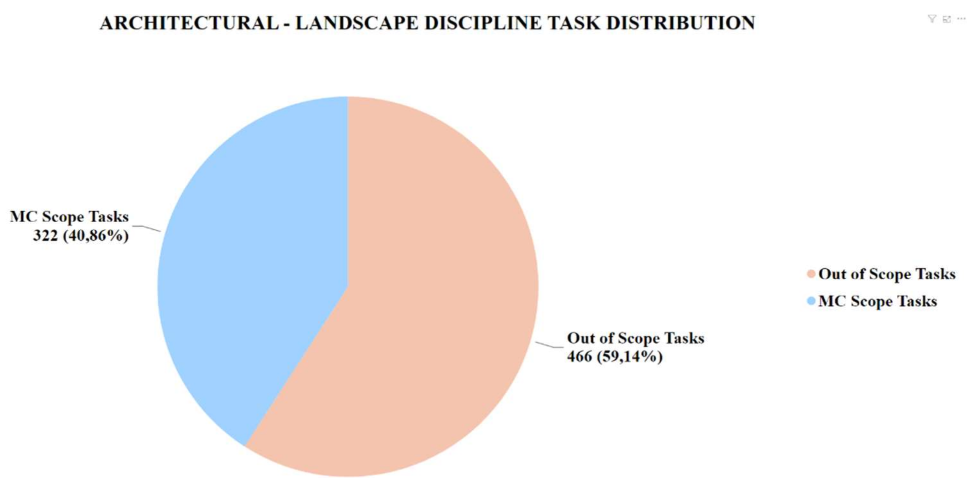


Figure 4.24. Task classification distributions of Architectural–ID and Architectural–Landscape disciplines for the overall project. Results indicate that more than half of the main contractor's time is spent on out-of-scope tasks for both disciplines.

"Out of Scope SC Model vs SD Verification" is identified as an important out of scope task during the analyses. This out of scope task classification is not discipline specific like other out of scope task classifications, instead it includes various disciplines. SC means subcontractor, while SD stands for shop drawing. So, this task classification includes works of comparing and validating models with drawings that came from the subcontractors. Validation and comparison work done under this category was related with finding out if the drawings were originated solely from BIM models or whether CAD edits were done on the drawings. All drawings were individually controlled for drawings that were submitted as small packages. On the other hand, for larger submission packages, random drawings based on several properties were picked for control. If any of these randomly chosen drawings were problematic, the whole submission package was rejected. 953 hours, which corresponds to %1.74 of time spent on the whole project, were spent on works belonging to this classification. Detailed analysis of this task classification based on project plots revealed that majority of the works on this category belongs to interior design discipline (Architectural–ID) for both project plots (Figure 4.25). This result further supports the interpretation of data that the interior design had serious problems, especially with the subcontractor, in return forced the main contractor to intervene the process and compare the submitted shop drawings with subcontractors' models for validation.

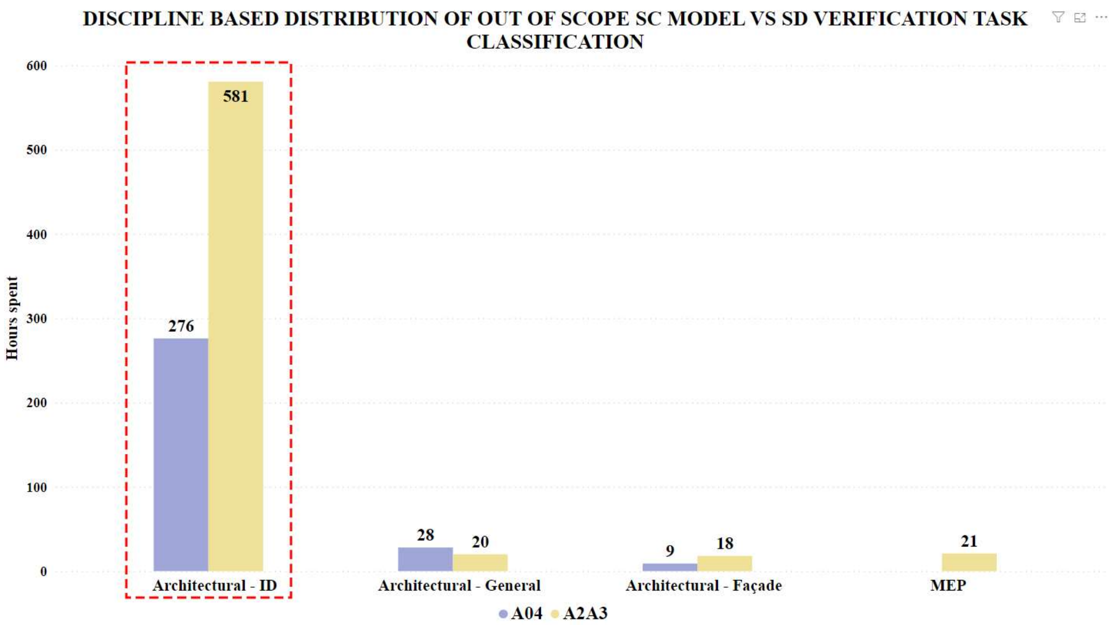


Figure 4.25. Analysis of data indicates that the Architectural-ID is the most problematic discipline for out of scope SC model vs SD verification task classification.

Previous analyses in this chapter investigate the project's BIM performance mainly from the time perspective. The analysis shows evidence to possible problems in project plots that led to the emergence of out of scope tasks. Even if these problems did not result in out of scope tasks, they resulted with significantly higher time spent on in-scope tasks, like constant design changes resulted in rework on previously done and submitted drawings. Findings from conducted interviews are mostly in line with the assumptions based on the data analyses and confirmed presence of serious problems in various disciplines. Problems encountered and effects of these problems on project performance are discussed in Interviews (4.4.) section of the thesis. This situation resulted with an increase in the overall project duration. However, these problems not only result in increased project duration, but also increased overall project cost. Increased project duration means longer working times, thus higher employee costs. Data available from the dataset is not sufficient to calculate the total increase in project cost caused by these problems, yet it allows us to evaluate these problems' impact on total cost partially, at least in terms of employee costs. It is possible to analyze employees' working hours according to task classifications and disciplines, so that out of scope task ratios can be found for each employee (Figure 4.26). There are only six employees (P3, P5, P6, P12, P14 and P16) that did not perform any out of scope tasks during the project, while ten employees performed out of scope tasks. Results indicated that P10 has the highest amount of time spent on out of scope tasks with 1488 hours, followed by P9 with 857 hours and P8 with 649 hours. P9 not only has higher amount of time spent on out of scope tasks but also has the highest ratio for out of scope tasks with %50.78. This ratio drastically is higher compared to other employees; closest employees are P2 with out-of-scope task ratio of %27.44, and P10 with out of scope task ratio of %21.26.

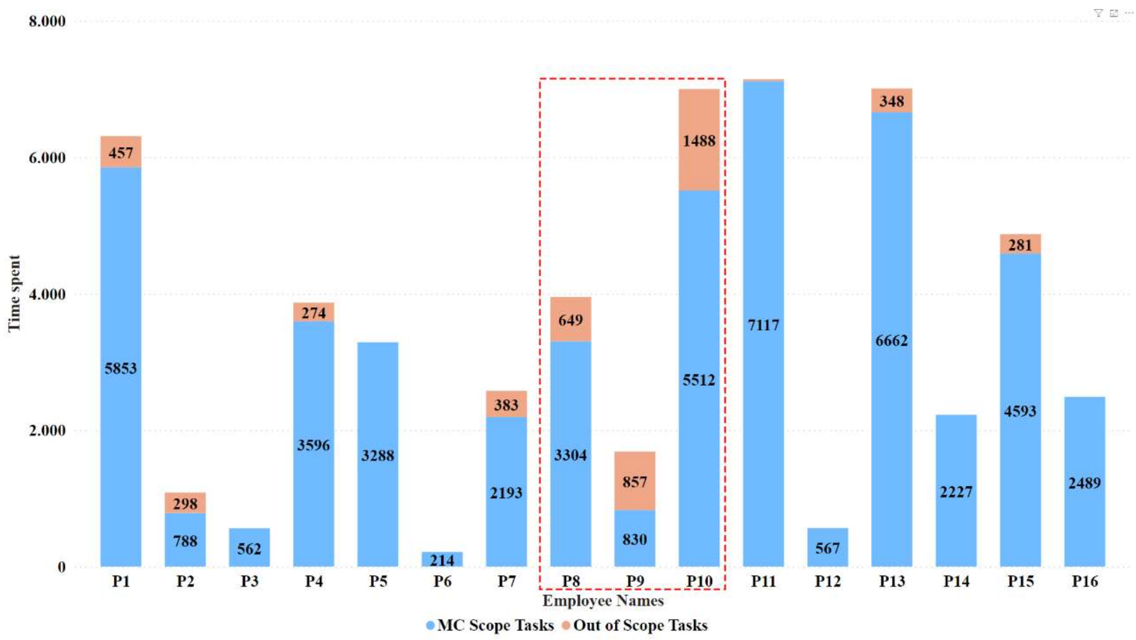


Figure 4.26. Task classification distributions for each employee for overall project. Analysis indicates that significant amount of worker hours was spent on out of scope tasks. P9 spent more than half of his/her time on out of scope tasks, followed by P2 with %27,44, and P10 with %21,26.

As the next step, employee based spent time analyses were carried out for three disciplines (Architectural–Landscape, Architectural–ID, MEP) that were identified as problematic in earlier analyses. Main reason of these analyses was to investigate whether out of scope tasks were distributed among the already appointed personnel for doing in scope tasks, or new employees were specifically assigned to complete these tasks. Figure 4.27. shows that for Architectural–ID discipline, it can be clearly seen that employee P10 was the person that specifically focused on out of scope tasks for that discipline. P10 spent 802 hours for out of scope tasks, which corresponds to %94.24 of time he/she spent for tasks related with that discipline.

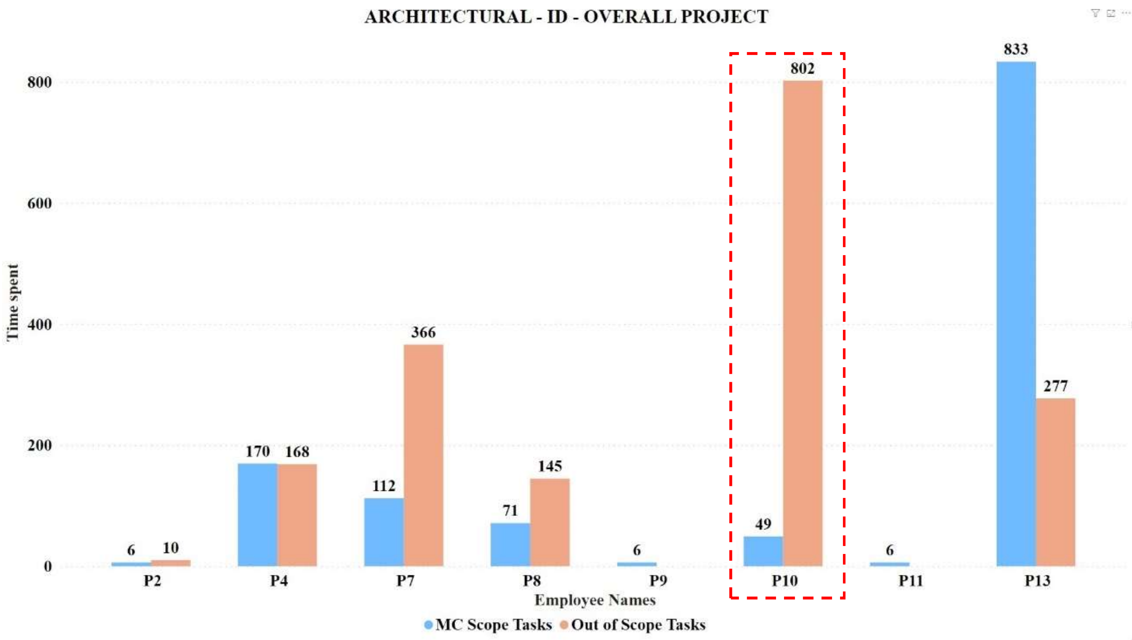


Figure 4.27. Overall Architectural – ID discipline task distribution for each employee. Figure indicates that P10 (indicated with red rectangle) specifically dealt with out of scope tasks for that discipline. Three employees (P7, P8 and P10) spent more than half of their time dealing with out of scope tasks for the Architectural-ID discipline.

Plot specific results for Architectural-ID discipline revealed important information (Figure 4.28.). For A04 plot, there were two employees (P7 and P13) doing most of the work (%92.61). Both P7 and P13 had similar hours spent and out of scope and in scope task ratios. However, A2A3 analysis results do not show such a balanced workload distribution. On A2A3 plot, employee P10 was specifically focusing on out of scope tasks, spending %96.16 of overall time he/she spent for Architectural–ID discipline on A2A3 plot. Interviews revealed that, P10 was specifically assigned to deal with out of scope tasks of Architectural-ID discipline on A04 plot, because he/she was a qualified employee whose skills on these tasks could be trusted and is also easy to communicate.

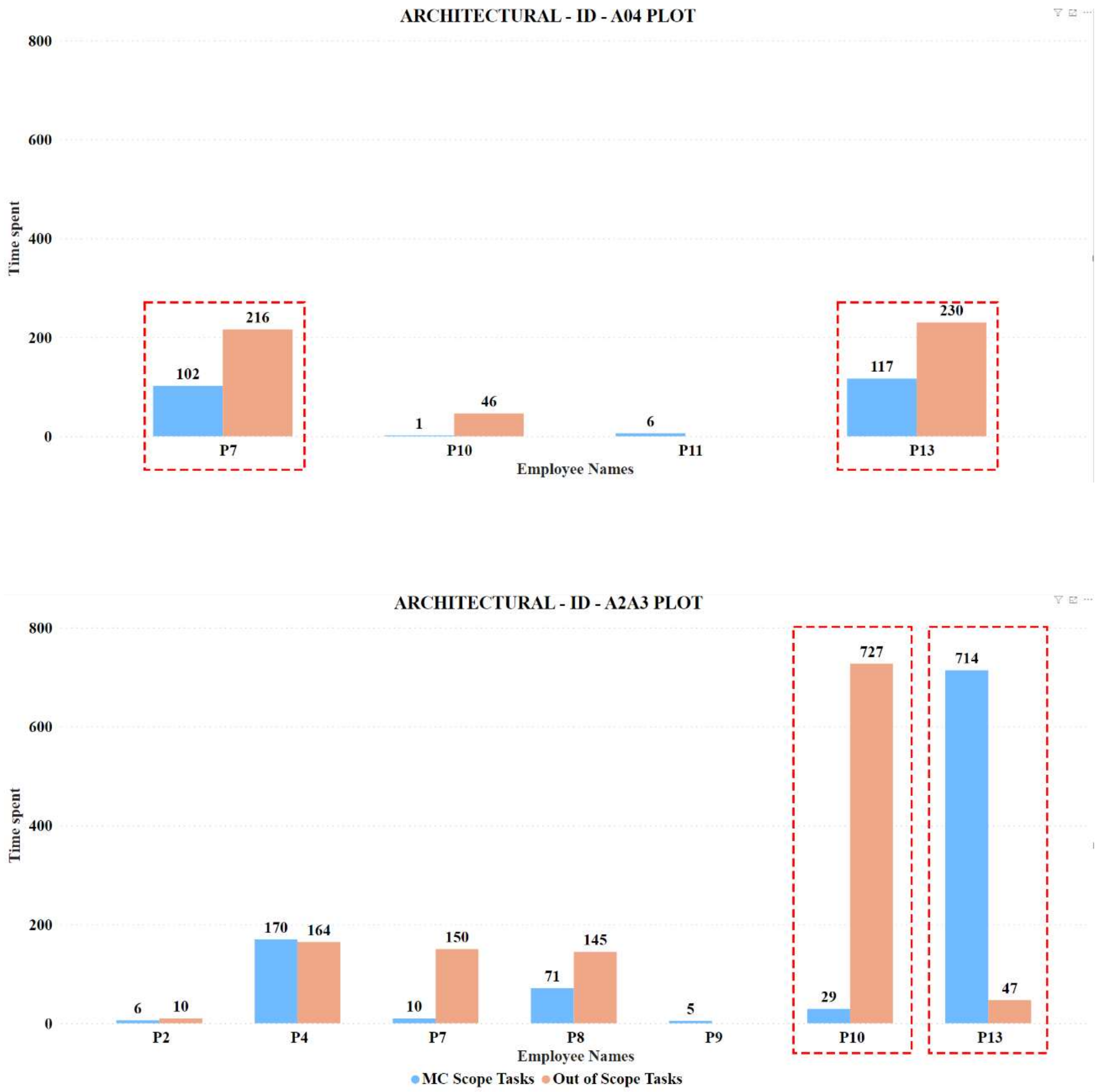


Figure 4.28. Plot based Architectural–ID discipline task distribution for each employee. Figure indicates that while A04 plot has more balanced task distribution between P7 and P13, A2A3 plot showed uneven distribution with P10 focusing nearly solely on out-of-scope tasks and P13 focusing mainly on in scope tasks.

Moving on to Architectural–Landscape discipline, overall project results are similar to Architectural–ID discipline's results for A04 plot. Figure 4.29. shows Architectural-ID discipline task distribution for each employee for the overall project. Most of the work (%93,85) was done by two employees, P8 and P11, but unlike the results from A04, while in scope task distribution is quite balanced between two employees, nearly all of out-of-scope tasks were done by P8.

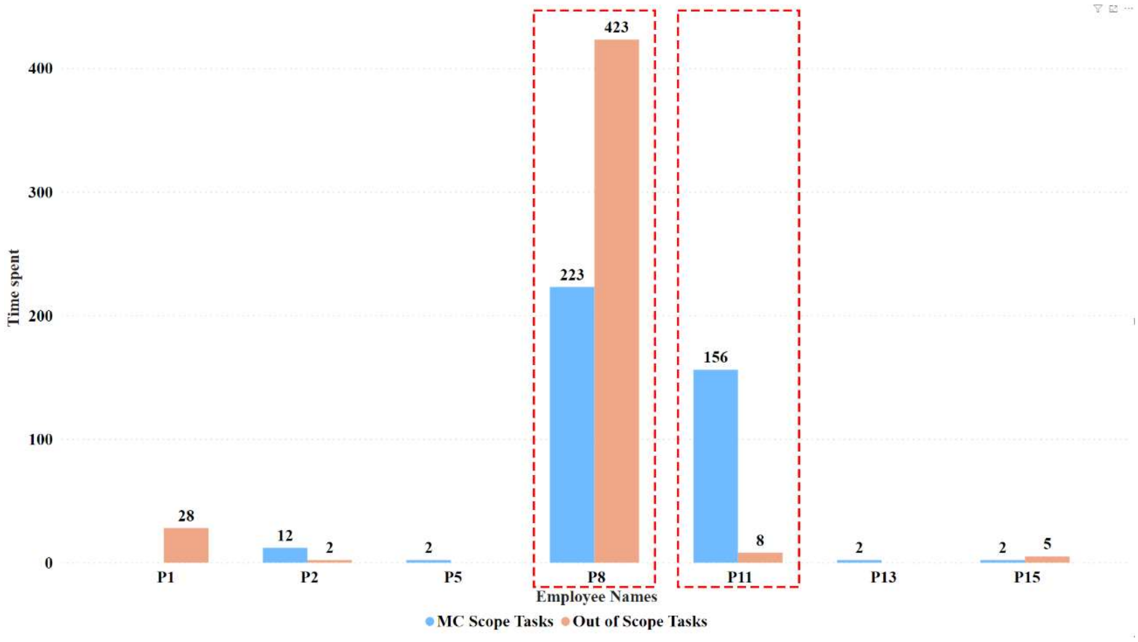


Figure 4.29. Overall project Architectural – Landscape discipline task distribution for each employee results show one employee (P8) specifically dealing with out of scope tasks.

Detailed analysis of MEP discipline showed similar results to previous two disciplines. Figure 4.30. shows MEP discipline task distribution for each employee based on overall project. There is one employee, P9, who is specifically focusing on completing out of scope tasks. P1 was mostly focusing on in scope tasks and significantly higher time spent compared to other employees. Detailed analysis of his/her workhours revealed that %93,15 of total time he/she spent for MEP discipline was spent on A04 plot, which corresponds to 5764 hours. At the same time, time spent by P1 for MEP discipline on A04 plot corresponds to %90,97 of the total time spent by all employees for MEP discipline on A04 plot. Thus, understanding the responsibilities and task scope of this employee should help us gain better understanding about the MEP performance on A04 plot. This situation is specifically asked in interviews and discussed in detail in Interviews (4.4) section.

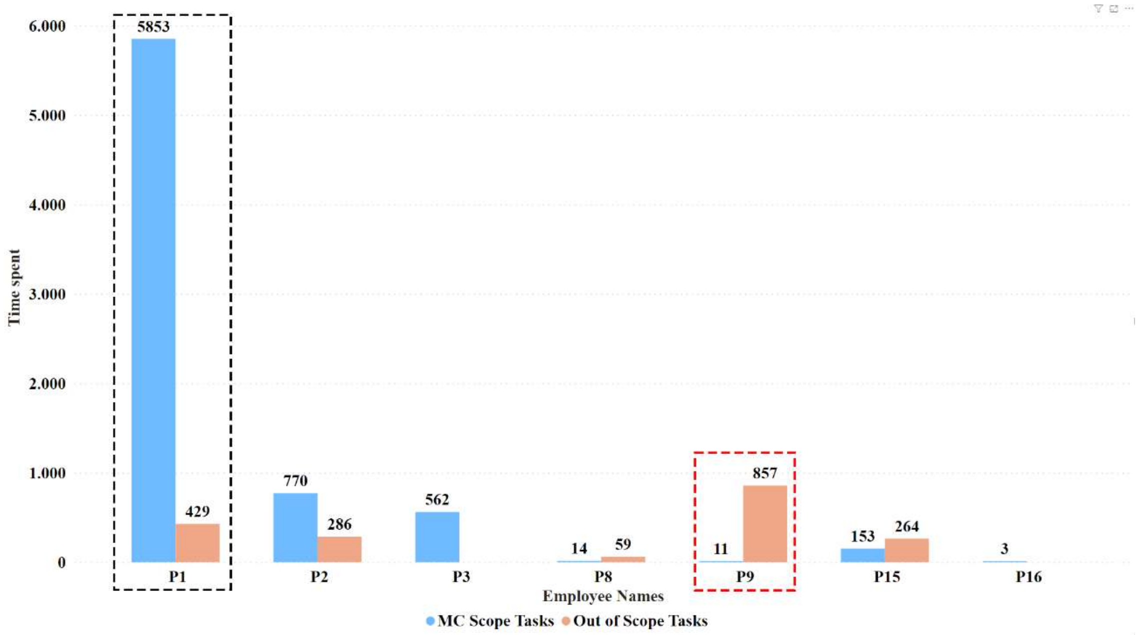


Figure 4.30. Overall project MEP discipline task distribution for each employee showing one employee (P9) was specifically tasked for dealing with out of scope tasks.

Results show that for each of these three disciplines, there were some employees who specifically focused on out of scope tasks and spent significant amount of their time on these tasks. This situation points out to a serious issue since these tasks were stealing the workforce that would otherwise be used for in scope tasks and. As mentioned earlier, this resulted in increased overall cost and time of the project from the perspective of the main contractor, thus negatively affected BIM performance. Dataset provided by main contractor is not sufficient to evaluate these tasks' total impact on overall project cost because of several reasons. For example, some of these out of scope tasks resulted in changes that led to rework on already completed and submitted drawings, thus increased project duration even more. There were also additional material costs (paper costs of printed drawings etc.) caused by these out of scope tasks. The total impact of these out of scope tasks on overall project cost cannot be calculated with information available within the provided dataset. However, these out of scope tasks' impact on main contractor firm can be calculated to some extent, at least in terms of employee costs, by combining employee costs from human resources table with task classification distributions of each employee from Figure 4.26. Table 4.11 below shows calculated employee cost of out of scope tasks for each employee and for the whole project team. Three employees (P3, P6 and P12) are missing in this table since provided human resources table does not contain information about these employees. Results indicate that employee cost for out of scope tasks is 398355,71 dollars which corresponds to %12.60 of total employee cost. Since interviews with main contractor firm revealed that any rate above %5 is considered “significant” according to their standards, it is safe to say that these out of scope tasks had a significant effect on cost from the main contractor’s perspective.

Table 4.11. Calculated employee cost of out of scope tasks. Table shows these tasks’ significant impact on costs when examined in terms of time spent on these tasks relative to total time spent on project.

Employee Name	Total Employee Cost	Out of Scope Ratio	Cost of Out of Scope Tasks
P1	266.818,08	7,24%	19.317,63
P2	431.953,54	27,44%	118.528,05
P4	258.524,02	7,07%	18.277,65
P5	194.828,78	0,00%	0,00
P7	184.800,78	14,87%	27.479,88
P8	179.077,14	16,41%	29.386,56
P9	196.875,85	50,78%	99.973,56
P10	246.422,22	21,26%	52.389,36
P11	227.864,43	0,36%	820,31
P13	411.100,41	4,96%	20.390,58
P14	163.443,54	0,00%	0,00
P15	204.369,73	5,77%	11.792,13
P16	194.872,19	0,00%	0,00
		TOTAL	**398.355,71**

Revision and Approved Drawing Information based Analysis

As mentioned in literature review chapter, there are studies suggesting RFI and change order numbers as BIM performance metrics. Dataset does not include information about RFI numbers or change order numbers, but ACONEX data include revision number for drawings which can potentially be leveraged for BIM performance analysis. In architectural drawings, revisions are the results of design changes and modifications. These design changes and modifications can be caused from various reasons including but not limited to conflicts between disciplines, client's request, regulation changes, and RFI's. These revisions may result with change orders if they are made on formally approved drawings or documents. Even if these revisions do not result in change orders, they require additional manpower and time to be done, thus potentially effecting the project time and cost. In this sense higher revision number may mean lower performance. By looking at ACONEX data, it is possible to understand how many revisions the drawings were revised before they were accepted. In the next step of analysis, ACONEX submissions were investigated according to disciplines for each project plot. Discipline categories that were used in categorization of ACONEX submissions are different from the ones in excel timesheets. There are total of 8 disciplines in the dataset which are Architectural, Civil Works, Special Systems, Electrical, Mechanical, Plumbing, MEP General and Structural. Before conducting any analyses, these categories are rearranged into 4 categories by merging some of the disciplines according to their relevance. Architectural and Structural remained unchanged, while MEP General, Plumbing, Mechanical and Electrical were merged into one discipline which we named as MEP. Civil Works and Special Systems were also merged into Civil Works & Special Systems discipline. After rearrangement of disciplines were completed, discipline based approved drawing numbers for each plot were investigated by filtering document submissions according to their status. Only document entries with "A – Approved" and "A – Approved with Comments" status were included. Figure 4.31 shows plot specific results for this analysis.

During this data analysis section, due to project properties and size, we expected plot A2A3 to have significantly higher time spent for all disciplines. This assumption also applied to drawing submissions. Thus, we expected plot A2A3 to have higher drawing submission numbers for every discipline. Figure 4.31. shows the number of approved drawings based on discipline for each project plot. Results are based on number of unique drawings for each discipline, different revisions for the same drawing were not included in this table. Results are in line with prior assumptions and analyses except for the "Structural" discipline. Number of approved drawings for MEP discipline supports the prior assumption of performance problems in A2A3 for that discipline. Previous analyses results did not indicate any potential performance problems on A04 for Structural discipline. However, approved drawings for Structural discipline on A04 plot were more than twice of the ones on A2A3 for the same discipline, which points out to the potential performance problems for that discipline on A04. Structural design could be problematic and as a result had undergone many changes during the project which led to need of new drawings. Even if the structural design was not problematic, changes made on design related with other disciplines and coordination problems may have resulted in changes in the structural design. Although results of this analysis indicate potential performance problems, it is not possible to draw any firm conclusions alone from the available data. Project plot based analysis of the distribution of approved drawings for each discipline according to revision numbers and interviews with main contractor (refer to Section 4.4) are conducted to reaching a more detailed and accurate conclusion about the situation.

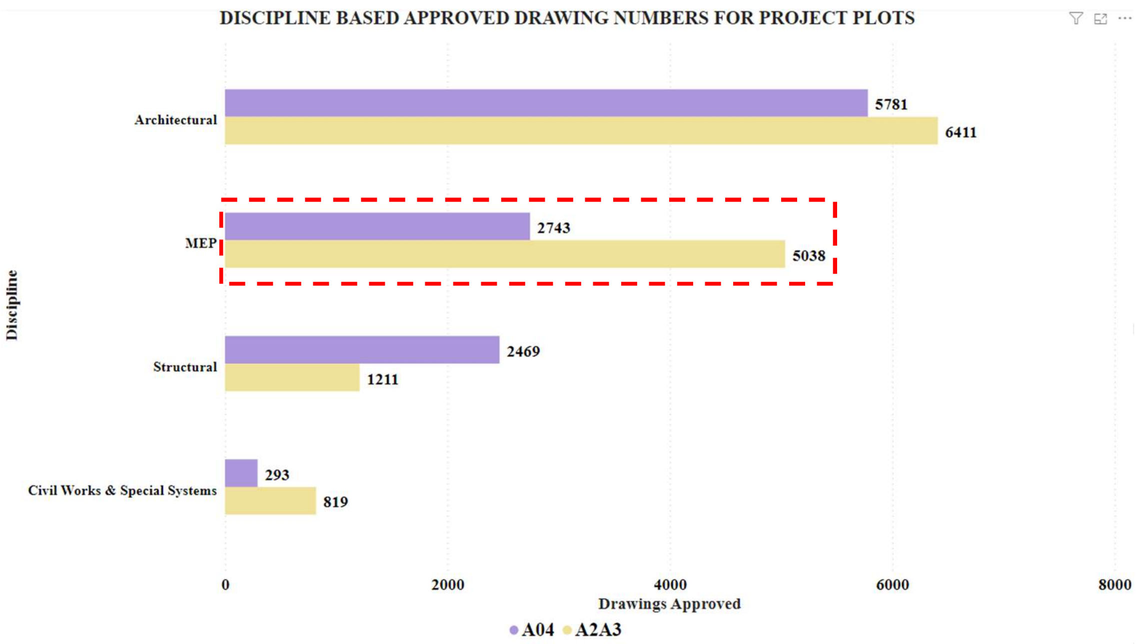


Figure 4.31. Approved drawing submissions for each project plot.

Two different methods were used for project plot based analysis of the distribution of approved drawings for each discipline according to revision numbers, (1) weighted average revision number and (2) distribution of drawings according to revision number. Weighted average revision number formula is presented below.

$$Weighted\ Average = \frac{\sum_{i=0}^{n}(i * DN_{Rev.i})}{DN_{Total}}$$

According to the formula, weighted average revision number is calculated by multiplying each revision number (i) by number of drawings approved on that revision number ($DN_{Rev.i}$), then results are summed and divided by the total number of drawings (DN_{Total}).

First, the analysis is completed from the perspective of the MEP discipline. Figure 4.32. shows distribution of approved drawings according to revision number for each project plot based on MEP discipline. There were no drawings that were accepted without revision on both project plots. On A2A3, drawings that were accepted after two revisions have the highest percentage with %34.58, followed by %33,27 for one revision, %18.82 for three revisions and %13,33 for drawings accepted after four or more revisions. On A04, highest percentage belongs to drawings accepted after one revision with %34,27, followed by %31.64 for two revisions, %20,89 for three revisions and %13,23 for drawings accepted after four or more revisions. Highest revision number for approved drawings is seven on both project plots. Weighted average revision number for MEP discipline is calculated as 2,1802 for A2A3 and 2,21 for A04. In light of the prior analyses, we see that there is a clear inconsistency within the MEP discipline-based results. Analyses based on approved drawing numbers, out of scope/in scope task distribution as well as time graph for MEP discipline indicate potential performance problems on A2A3 plot. On the contrary discipline based time spent analysis indicated the opposite and showed significantly higher time spent on A04 compared to A2A3, which pointed out to potential performance problems on A04. On the other hand, project plot based percentage distribution and weighted average revision number results of approved drawings for MEP discipline does not indicate any performance problems or significant difference between project plots. These different interpretations could be caused by a number of reasons. There may be problems within the dataset in the MEP discipline related information, such as missing data or miscategorized data. In the end, interviews were done with the main contractor, to better understand and evaluate this situation and what caused these different interpretations to occur. Findings from these interviews are discussed in “Interviews” section.

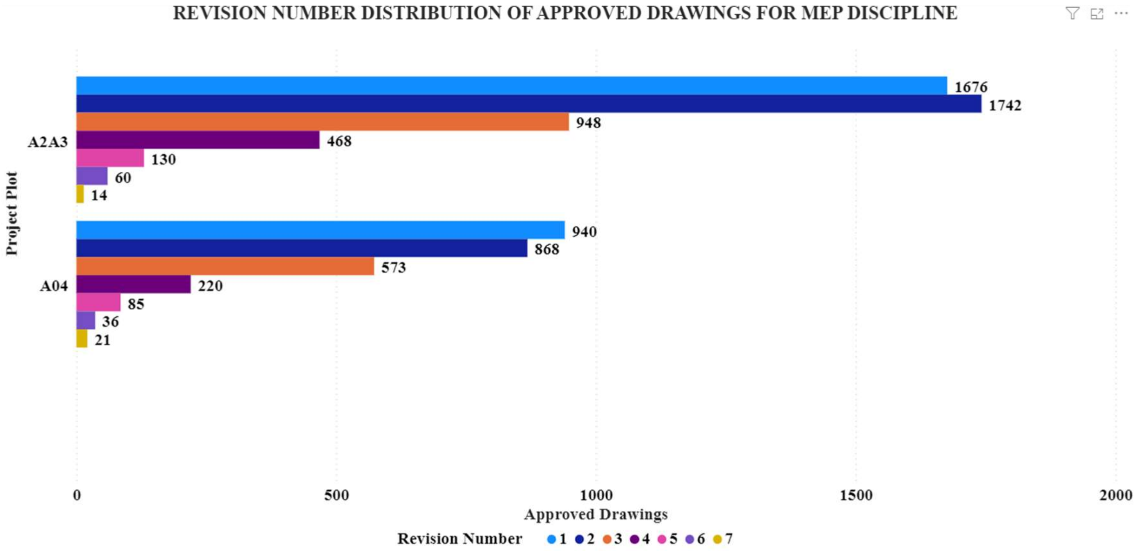


Figure 4.32. Revision number distribution of approved drawings for MEP discipline. Results showing significantly higher number of drawings on A2A3 plot but similar revision number rates.

In the next stage, distribution of approved drawings according to revision number for each project plot based on Structural discipline were investigated. Here, as in the MEP discipline, all drawings were revised at least once before they were accepted. Figure 4.33. shows distribution of approved drawings for structural discipline based on revision numbers for each project plot. Results pointed out that on A2A3, more than two thirds of approved drawings (%68,29) were accepted after one revision. Drawings approved after second revision correspond to %22,46 while drawings approved after third revision have account for %6,19. Only %3,06 of the approved drawings required four or more revisions. Highest revision number for approved Structural drawings on A2A3 plot was five compared to the seven on A04 plot. Structural discipline on the A2A3 plot is the only discipline that does not have more than five revisions for any of the approved drawings. All other disciplines on both plots as well as Structural discipline on the A04 plot have drawings revised six or seven times before being approved. On the other hand, results on A04 plot support the performance problem assumption made for that plot based on number of drawings approved. The percentage of drawings that were approved after the first revision is significantly lower, corresponding to %48,68 compared to %68,29 on A2A3. Also, the percentage of drawings that were approved after the second revision and third revision increase significantly. On A04, %31,83 of the drawings approved after the second revision compared to %22,46 on A2A3 while %13,97 of the drawings required three revisions before being accepted compared to %6,19. Lastly, %5,52 of the drawings revised four or more times before approved. Weighted average revision numbers are also indicate potential performance problems for structural discipline on A04. Calculated weighted average revision number is 1,7914 on A04 which is significantly higher compared to 1,4541 on A2A3 plot. There may be several reasons for this situation. Structural design of the A2A3 plot could be more complete compared to structural design of A04, thus less revisions were required during the completion of shop drawings since design changed less on A2A3 plot. Another possible explanation may be that the changes in other disciplines may have major impacts on structural design which led to major changes in structural design of A04. Since prior time based discipline and task classification analyses did not reveal any results that coincide with the results of this analysis, it is not possible to draw a firm conclusion. Therefore, interviews are conducted with main contractor firm to verify interpretations about the structural discipline's performance for project plots. These interviews and their results are described in detail in "Interviews" section.

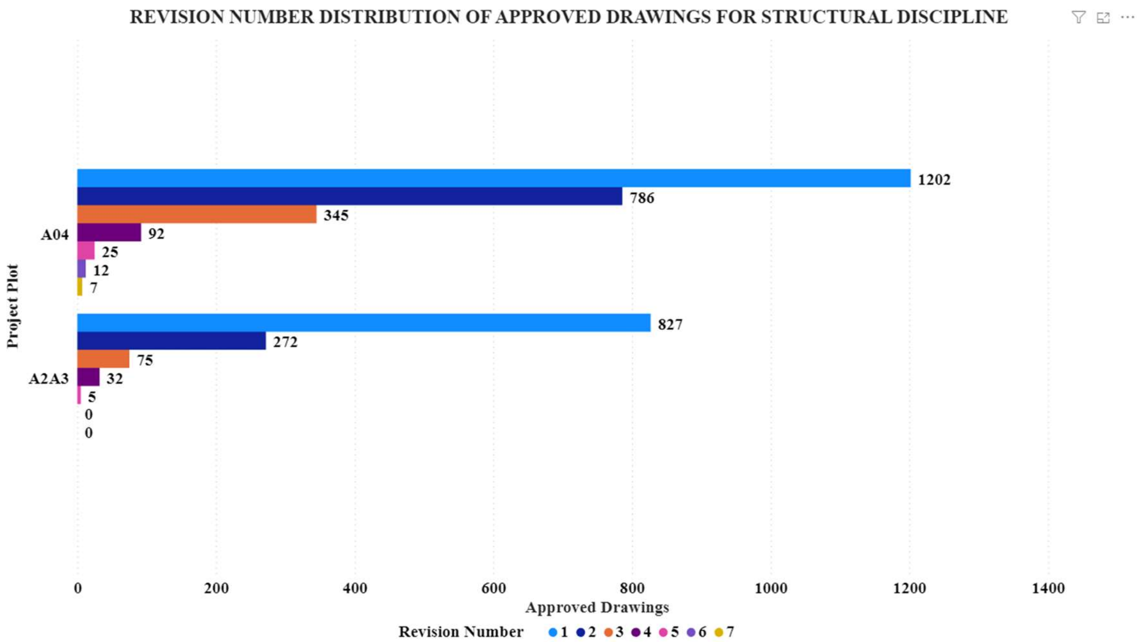


Figure 4.33. Revision number distribution of approved drawings for structural discipline. Results showing significantly higher number of drawings and higher revision number overall on A04 plot.

Last discipline that was analyzed based on revision numbers is Architectural discipline. Prior analyses based on task classifications and time spent per discipline indicated that Architectural discipline, especially the interior design part, had performance problems on both project plots. Findings of the revision number distribution analysis of approved drawings revealed additional information about the performance of Architectural discipline on each project plot (Figure 4.34). Results show that on A2A3 plot, drawings that were accepted after one revision have the highest percentage with %41,38, followed by %28,14 for two revisions and %15,44 for three revisions. Drawings that were approved after four or more revisions make up %15,04 of total drawings approved for architectural discipline on A2A3 plot. Results for A04 plot indicate a different situation, with highest percentage belonging to drawings approved after two revisions (%34,98) rather than the drawings approved after one revision as in A2A3 plot. Compared to A2A3 plot, rate of drawings accepted after the first revision is lower (%26,93 compared to %41,38 on A2A3) while rate of drawings accepted after the third revision is higher (%21,58 compared to %15,44 on A2A3). Also, rate of drawings that required four or more revisions before being approved is higher on A04 plot compared to A2A3 plot. Weighted average revision numbers also support this situation. Calculated weighted average revision number of approved drawings for architectural discipline is 2,3758 on A04 plot, which is notably higher compared to 2,1240 on A2A3 plot. Overall results for architectural discipline indicate that drawings on A04 plot generally required more revisions before being approved. This indicates potential performance problems or more problematic design on A04 plot. As in structural discipline, this situation could be caused by several reasons such as incomplete architectural design or an architectural design that had undergone major changes. In addition to these possible reasons, considering the results for the structural and architectural disciplines, it is possible that the major changes or problems encountered in one of these disciplines may have caused changes or introduced problems in the other, and in this respect, the results may be related to each other.

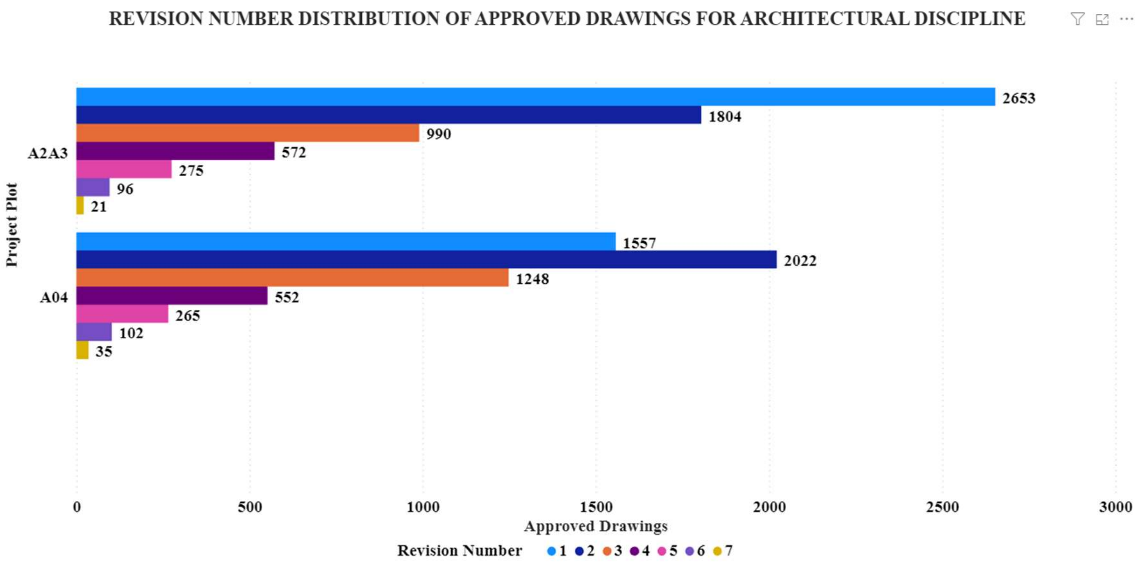


Figure 4.34. Revision number distribution of approved drawings for architectural discipline showing drawings on A04 plot required more revisions.

4.4. Interviews with the Main Contractor Firm

Interviews are conducted with project participants to identify the problems in the project and reasons behind it. During these interviews, data analysis results are also shared with participants to determine whether these results correspond to their experiences in the project. In this chapter, conducted interviews and findings based on the interviews are thoroughly explained. Findings from the interviews are discussed under four main categories: (1) *benefits of BIM implementation*, (2) *BIM barriers*, (3) *BIM Execution Plans' effect on BIM performance* and (4) *problems affecting the BIM performance.*

4.4.1. Benefits of BIM Implementation

Interviews revealed that there are various benefits of BIM implementation that were perceived by main contractor during the project. BIM manager (BM) stated that, easy and reliable access to information and enhanced information sharing with the help of server and cloud systems are some of the key benefits of BIM implementation in the project.

"01:24:12 R: Were there any perceived benefits from using BIM on this project? If so, what were the benefits?
01:24:20: BM: It definitely helped tremendously. Especially in such a project, they could not solve it without BIM. Because in some cases, the company may lose its drawing, because there is no server layout. BIM is not just about modeling, we went and created the subcontractor's server system. Because if there is no proper registration and server system, it cannot send me proper information, it may be wrong or incomplete.**"**

According to the BM, BIM brings an order to a construction project by providing a single source of truth. Establishing a single source of truth means all individuals can access the same data located in a central database. Everyone having access to same and unified data helps to minimize miscommunications and eases coordination.

"01:24:52 BM: … BIM brings order to a construction project; it brings a single source of truth. Consider a project airport in which 3000 white-collar workers and 30000 workers are employed, the value of this is invaluable in such a project. I myself have experienced what happens when this "single source of truth" situation cannot be achieved in such a project, it is officially a "chaos".**"**

BIM manager stated that one of the biggest benefits of BIM implementation in the project was enhanced coordination and communication.

"01:26:16 BM: …For example, coordination. How will you coordinate without a model in a project with so many problems and frequent design changes? Thanks to the use of BIM, problems can be solved before moving on to the site, imagine that you are trying to solve these coordination problems on-site in such a large-scale project. And such events happen even in large companies in the industry, perhaps even in the construction firms rated at ENR 100. BIM provides a great advantage in this regard, providing improved coordination to eliminate or at least minimize the problems prior to on-site work.**"**

4.4.2. Barriers to the BIM Adoption

Several barriers to the BIM adoption are identified during the interviews. Culture and resistance to change is the most important barrier according to the BIM manager. BIM manager stated that overcoming people's resistance, changing their behaviors and attitude towards BIM are crucial to successfully adopt BIM into the project. According to him, people who are inexperienced about the BIM process think that BIM is slower compared to the traditional methods and makes things harder.

“01:28:53 BM: Culture and changing this culture was the most important step here. People are a bit narrow-minded about some issues, considering the time spent on work in BIM as if it takes more time, without looking at the whole process. While using more traditional methods, they think that it is a faster process when submitting works piece by piece and independently without verification, but when looking at the whole process, they do not realize that BIM offers a faster and more coordinated solution, or they do not want to notice. It takes time to impose this on people. Gaining trust and breaking resistance to this culture and technological change take time. In the construction industry, you need to overcome people's egos in order to gain this trust and break the resistance, because in general, senior managers, which we can call the old generation, are the people who show such resistance.**”**

He also stated that at one-point resistance to BIM increased so much that the idea of abandoning the BIM implementation in the project was discussed.

“01:31:20 BM: In fact, this is such a situation that, at one stage of the project, it was discussed whether we should convert the entire project to 2D, a whole project. You have to deal with situations like this.**”**

Lack of BIM knowledge and BIM competency is another important barrier to BIM adoption according to the BIM manager of the project. People with insufficient knowledge and competency tend to blame the BIM process rather than accepting their mistakes or asking for assistance.

“01:32:40 BM: Competency is a big issue. Especially since the construction industry is a job where sociality is a bit prominent, I have seen many employees who are not technically competent for that position, but who are there thanks to their social skills. For example, there are people who do not do their job properly and try to get rid of the problem by blaming BIM. There are many people who try to pin human errors to BIM.**”**

This competency problem was evident for the landscape contractor. Even though the landscape contractor knew the problem was caused by their incompetency, they refused to accept it or ask for help, instead tried to manipulate their role and tasks in the project. This situation resulted in delayed tasks thus increasing in overall project duration.

> **"01:36:17 BM:** Some project participants do not want help even though they cannot do it, there are those who say they can solve it without help even when they cannot, and there are those who insisted to not do the jobs because they are incompetent. For example, the landscape subcontractor persisted for 6 months, but in the end, after much discussion admitted that he could not do the job and gave us the responsibility of BIM model part as an out of scope job.**"**

Last barrier that is stated by BIM manager is about the roles and responsibilities. Some people may not fully understand their role in BIM implementation or the role and objective of BIM in the project.

> **"01:35:40 BM:** People and companies do not know or understand what they are signing when signing contracts. They don't make an investment in BIM; they see it as an additional effort rather than adopting it and implementing it properly. They see it as a visualization tool.**"**

4.4.3. BIM Execution Plans' Effect on BIM Performance

At the BIM implementation part of the thesis, we stated that a well-defined and executed BEP improves the BIM performance in several ways and is a must for the success of a BIM project. During the interviews, BIM manager confirmed that statement and stated that BEP and other documents integrated into it (like documents handover strategies) is a must to achieve best performance in BIM projects.

> **"01:38:06 BM:** Without BEP, you cannot progress properly. We can say that BEP is like a holy book for us. The more detailed and advanced the BEP is prepared, the more positively it affects BIM performance. Of course, it would not be right to limit it only to BEP, but also other detail documents that work integrated with BEP provide great benefits. For example, handover strategies are an example of this. We can say that a detailed and advanced BEP fed by such detail documents is a necessity to ensure maximum BIM performance in projects.**"**

According to the BM, even though BEP in this project is the most detailed one among the projects he has worked on so far, it still had room for improvement, and should be improved. But this situation does not make the project's BEP inadequate, in fact he sees the BEP as adequate, and stated that it improved BIM performance a lot.

> **"01:36:50 R:** So, can we say that BEP has a positive impact on BIM performance in the project?
> **01:37:03:** Absolutely, we can say one hundred percent. But I can still say that there is not enough detail. We have completed the deficiencies here with booklets, if I had the opportunity to write again, I would write it again in more detail. Still, I think it was an adequate BEP. Even the executive director of the project owner came by saying, "What are you doing here, I hear this project a lot", at least in this respect, I can say that it is a successful BEP.**"**

4.4.4. Problems Affecting the BIM Performance in the Project

Interviews revealed project problems that affected the project BIM performance. Most of the problems are in line with assumptions made during the data analysis part of the project. In this part, problems that were identified from the interviews and how these problems correspond with the assumptions from data analysis are discussed in detail.

Contractual Problems

According to BIM manager, there were contractual problems, especially in terms of roles and responsibilities, that negatively impacted the BIM performance. He stated that main contractor was responsible from the "build" part of a "design-bid-build" contract, but they had been asked to carry out the tasks that did not belong to them according to the contract type. The main contractor was also not given full authority they needed to perform these tasks effectively either.

> **"01:21:40 BM:** Actually, our contract is only about the build part. But in practice, the work we did was as if we had signed a design and build contract. This is a huge problem. If you are assuming a responsibility, you must also give authority accordingly. If you are assigning the work of a designer to us, the mechanism of having us make the design that he needs to do, then send it to him and get approval from him is very wrong. We may not have undertaken all the design tasks, but we did the main job that required the most time

and money. If I'm designing, it means that I'm the designer now, I have to have his authority as well as his responsibilities."

BIM manager stated that the situation about role and responsibilities caused serious problems about contract and project management, like increased amount of rework, thus led to increased project duration. Because of contractual limitations, in some situations they could not delay the drawing submission and had to complete drawings according to the data they had, even though they knew the design would change and they would have to do the rework after, if their part was affected from the changes. On the other hand, in some cases, the out of scope tasks that were originally in the scope of the designer firm, but had to be undertaken by the main contractor, prevented the main contractor from doing tasks that were in their scope. Because the out of scope design tasks had to be completed prior to the in scope tasks. Thus, not only time spent for out of scope tasks but also the time spent for tasks that were in main contractor's scope increased significantly.

"01:22:45 BM: For example, we worked in a place for three weeks, we agreed with the architect, although it was stated that this would be done, the new project that came to us after we finished and sent our work had nothing to do with what we did. While we were the main contractor on the one hand, we were also officially subcontracting the design. And these jobs are very interconnected, you can't do your main contracting job until the job you are doing as a design subcontractor is successfully completed. There was such an absurd situation."

Design and Coordination Problems

Interviews revealed that both project plots (A2A3 and A04) had problems with their design, but A2A3 plot's design was more problematic compared to A04 plot. The main reasons for the problems in A2A3 were (a) the change of not only the design but also the designer, and (b) the discrepancies between the new design and interior design (ID), which was completed and submitted according to the old design. Also the new designer did not make necessary coordination between new design and ID. These findings are in line with the assumption made from the results of data analyses, which suggests that A2A3 was more problematic in design, especially in ID section. These coordination problems and constant changes in general design and ID also resulted in significant problems and changes in MEP discipline.

> **"01:18:01 BM:** It was problematic in both designs. But A2A3 was a more problematic project by design. The A2A3 designer we worked with joined the project later, the first design was made by another company years ago and was not fully completed. In the meantime, the controls and coordination between the later design changes and interior design have not been made. In fact, even though the new designer doesn't seem to be at fault in this situation, if I were in their place, I would make the necessary coordination and controls when I got the job, secure myself, and then send it to the contractor companies.**"**

On A2A3 plot, coordination problems, owner's demands, and more and extensive design changes combined with the complexity of the design resulted in more issues affecting the BIM performance negatively compared to A04. The BIM manager stated that while a very large part of the project can be completed with a single typical floor plan solution on the A04 plot, there were 6 typical floor plans for A2A3 even before the changes, and this number approached 40 as a result of the changes. This situation resulted in significant amount of time spent for out of scope tasks and revisions on drawings.

> **"00:34:39 BM:** For example, you solve one typical floor plan for A04, then this continues all the way up to the floor where the duplexes are, then you solve the duplexes there. So you are solving a very large part of the project with a single typical floor plan. A2A3 had 6 typical floor plans. At first, a design was sent to us as if there was only one typical floor plan for the buildings, but the columns got smaller as the load decreased as we went up to the upper floors, and the employer wanted to use this as it increased the usable area. This caused details to change and led to working on about 40 typical floor plans, far more than a single typical floor. In addition, A2A3 had more changes in design, its coordination was more problematic than A04, and some change requests from the employer caused additional problems in A2A3 in general.**"**

Another discipline that was considered to have performance problems according to the analyses results was MEP. Results of the data analyses indicated that A2A3 had more problems that led to significant amount of time spent on out of scope tasks, while A04 had no out of scope tasks. Also, the MEP based time graph on A2A3 plot was showing uneven distribution with massive gaps in-between working periods when compared to other disciplines' graphs for the same plot. Findings from the interviews are in line with the assumptions made about A2A3's MEP performance. During the interviews, BIM manager stated that A2A3 plot's design was more "premature" compared to A04, which led to significant problems with MEP discipline.

> **"00:09:51 BM:** In fact, the most basic thing we can say as the MEP between A2A3 and A04 is that the design is more premature, less advanced in A2A3. Generally speaking, the design of the A04 is better. For example, in A2A3, we had to redesign four times only for basements. We did not experience such a situation in the A04.**"**

Besides the problems caused by premature and incomplete design on A2A3, there were also problems caused by the MEP subcontractor. Delay on subcontractor's MEP coordinator appointment and the incompetency of appointed coordinator caused delays in tasks and instead of advancing, project had regressed on that period. In the end, main contractor firm had to shift its own employees to the subcontractor, which caused significant changes in planning and task distribution of other employees. This employee shifting was also the reason for lower number of hours spent in MEP data on A2A3 plot. Although the work continued, it was not entered in main contractor's data, since the coordinator was sent to subcontractor and appeared as working for the subcontractor. These findings coincide with the assumption made during the data analysis that lower MEP hours on A2A3 plot may be the result of incomplete data entry due to certain reasons.

> **"00:03:10 BM:** There were problems with the MEP subcontractor on A2A3, about finding employees too late for the coordinator task, we had to choose the best of the worst among the employees they found in the end. We understood that an employee who does not have the necessary competence should not be assigned under any circumstances. The subcontractor brought the coordinator 6 months late, the incoming coordinator worked for 6 months and the project got worse in that period. In the end, subcontractor fired the coordinator and requested from us to give them the coordinator in our team, who controls their work. Apart from that, we sent two more of our employees to the subcontractor, but they were sent later. This is the reason why the A2A3 section shows almost only out of scope works and the obvious lack of manhour, because the work did not progress much until this event, there were mostly out of scope works, then our data was not entered and

appeared as zero even though the work was carried out because the coordinator was sent to a subcontractor from us."

During the data analysis, results of the MEP discipline on A04 plot were contradicting with each other. In the end, the assumption made was that even if there were problems, it was much less compared to the A2A3. Interviews revealed that this assumption was wrong. BIM manager stated that there were problems related with MEP discipline on the A04 plot as well as the A2A3 plot. In fact, in some ways, A04 was more problematic compared to A2A3 plot in terms of MEP discipline. BIM manager also stated that, problems in the A04 plot were caused mainly by the management style of the project manager.

> **"BM:** … However, looking back at the project, I think from my own experience that even if we include the missing hour data for A2A3, we spend more time per square meter on MEP for A04. Of course, due to this lack of data, it is not 3 times as seen in the graphs, but maybe 1.5-2 times… The reason for so much time spent on MEP in A04 is the management style of the project manager. Here we see the impact of managerial differences among project managers on the work we do, which has a huge impact. In other words, in general, both projects are problematic, and from this point of view, A04 is a much more problematic project."

Since the findings from the interviews are contradicting with the result from the data analysis for A04's MEP, additional questions were asked to investigate the situation deeply and to find the reason behind such contradiction. Detailed investigation revealed that this situation is caused by the way MEP data is entered. Main contractor had to spent majority of its time on shop drawing controls with the project manager although they were not responsible from that task. However, project manager refused to classify them as out of scope tasks and insisted on categorizing them as in-scope coordination tasks, thus these works were entered as if they were the tasks that were in the scope of the main contractor. This fact led to the misinterpretation that there were no out of scope tasks for the MEP discipline on A04 plot.

> **"BM:** Actually, we shouldn't be spending that much time according to the normal procedure. We were not responsible from such thing as sitting down and examining the shop drawings for hours. Normally, what should happen is I submit my drawings and he

checks. But in the case of A04 MEP, we went through a process that took a lot of time, where the drawings were examined one by one and he questioned nearly everything, so to speak, that he used us as his right hand. As I said, this is a bit about the project manager. For example, the project manager in A2A3 wouldn't allow it, of course, there were special occasions where we did this kind of work, but he wouldn't allow it to be done throughout the project in this way.
R: Can we categorize these tasks as coordination?
BM: Actually, it is not a coordination task, but if you ask the project manager, he will say that we are working on coordination, and he will try to define it according to his own interests. Conflicts arise because of such situations. But this is not acceptable.
R: Then even though these tasks were not entered as out of scope in the data, in reality, they were out-of-scope tasks.
BM: Yes.**”**

In Data Analysis (4.3.) part, we mentioned that the results of revision number distribution analysis of approved drawings for structural discipline indicates that A04 plot’s structural design was more problematic than A2A3. Interviews revealed that both projects had problems in structural design, but A04 had more problems compared to A2A3. On A04, there were difficulties in obtaining models for statistical tests, and the structural design flaws that caused the design to fail in tests led to increase in number of revisions and changes.

“01:01:22 BM: A04 and A2A3 are both projects that have problems in terms of structural design. A04 was more problematic, especially in the roof part, there was a big crisis. The process of getting the previously made models of the design took very long and was troublesome. When we finally managed to get it, we saw that it did not pass the tests when we ran the models. Steel was failing, can you imagine?**”**

BIM manager also stated that the impact of the out of scope tasks were bigger than just employee costs. Their effects were not limited to the BIM department. These tasks affected overall project time and cost both directly and indirectly by creating a butterfly effect which were reflected in all departments and amplified the impacts.

> "**BM:** Maybe we can add that the 12% personnel cost impact you found belongs to the BIM department, we don't know exactly how the impact will be reflected on the field. The effects of the changes resulting from these out-of-scope works on logistics and employee hours cannot be calculated exactly. For example, you may have to hire additional employees and have them work overtime. As a result, the effects of these out of scope works on the project will create a butterfly effect, which will be reflected in all departments and cause higher impacts."

4.5. Discussion of the Results

A number of discipline and project plot specific problems are identified from the data analysis and explained throughout the Chapter 4. Results of the data analysis indicated that both A2A3 and A04 plots had problems going on for the architectural discipline, especially the interior design part of it, meanwhile the result of the analysis on A04 plot data suggested better performance compared to the A2A3 plot for the architecture discipline. Findings from the interviews are in line with what data analysis results suggested. Interviews revealed that both plots suffered from design changes that negatively impacted the performance. The A2A3 plot had significantly more problems, especially for interior design, mainly because of its more premature design compared to the A04 plot. The additionally identified reasons for the problems faced in the A2A3 plot can be summarized as: (a) change of the designer firm, (b) complete overhaul of the previous design while interior design being made according to the old design, and (c) the new designer firm not providing the necessary coordination according to the changes between the old and the new designs before sending them to main contractor.

Results from the approved drawing number and revision number distribution analysis led to the interpretation that there were structural problems on A04 plot while there was none on A2A3 plot. Findings from the interview confirmed the presence of structural problems in A04, while revealing that there were also structural problems in A2A3, although not as much as in A04. Thus, while analysis of the provided data was sufficient to reach the conclusion that A04 was problematic in terms of structural design, it was not adequate to identify that A2A3 was also problematic.

According to the analysis results, MEP was another discipline that was considered as having problems throughout the project. Analysis results clearly indicated that the A2A3 plot having problems in MEP discipline that affected the performance negatively, while results on the A04 plot were contradicting with each other. Although significantly higher time spent for the MEP discipline on the A04 plot (compared to A2A3 plot) suggested potential problems for the A04 plot, “task classification” based and “drawing number and revision distribution” based analyses results did not support this interpretation. Therefore, a definite interpretation could not be made about the MEP discipline performance in the A04 plot. Interviews revealed that both project plots had problems for MEP discipline from various perspectives. In the A04 plot, MEP discipline had problems based on management style and administrative choices of project manager. Meanwhile the problems in the A2A3 plot were generally caused by the more premature design compared to A04 and coordination issues.

Another important finding from the interviews is that it is very important, for the project’s BIM performance, to strictly define roles and responsibilities in contracts, and not to go beyond these defined roles and responsibilities during the project. Attempting to assign roles and responsibilities to project stakeholders other than those defined in contract, and not reflecting these alterations on the contract can seriously affect the BIM performance in a negative direction. One example for this situation is the work done for MEP discipline in A04 plot. Detailed investigation revealed that the MEP data for A04 plot is not entered to reflect the actual situation due to various reasons. For MEP discipline, although the majority of the tasks done in the A04 plot were out of scope, these tasks were entered as if they were in scope, due to the insistence of the project manager. This situation could not have been taken into account during the analysis since it was not stated in any way in the data provided for analysis. Thus, a healthy and firm conclusion could not be made for the A04 plot in terms of MEP discipline. This situation shows the importance of entering the data in detail and in a way that reflects the real situation. The same situation also gives an idea about the possible effects on the analysis results in cases where the data entered does not reflect the real situation, since it can potentially lead us to come to wrong conclusions.

Interviews also revealed several barriers to the BIM implementation: (a) Resistance to change, (b) level of BIM competency and BIM knowledge of stakeholders and project stakeholders, (c) diversion from the defined roles and responsibilities are the most important barriers that were identified during the interviews with the main contractor.

According to the interviews, despite the barriers and many problems encountered during the project, BIM also had a positive effect on the project performance in many aspects. BIM implementation enhanced the collaboration and communication between project stakeholders and provided improved coordination and information flow. BIM implementation also brought order to the project by providing a single source of truth. Interviews also showed the positive effects of BEP on BIM performance, and importance of well detailed and executed BEP for achieving the highest possible BIM performance.

CHAPTER 5

CONCLUSION

This study focused on evaluating BIM performance from a main contractor's perspective based on construction big data. The main research question of the study was "*How can we evaluate the BIM performance using big data from construction?*". The main purpose of this study was to introduce a systematical approach based on a proposed performance evaluation framework to evaluate BIM performance by using construction big data to answer this research question. While developing the evaluation framework, two research sub-questions were taken into consideration. Based on the first research sub-question, which was "*What are the performance metrics required for evaluating the BIM performance based on big data from construction?*", required performance metrics for BIM performance analysis are identified. Nineteen identified performance metrics that are categorized under six main performance measurement areas: (1) time, (2) out of scope tasks, (3) drawing revision numbers, (4) organization & people, (5) BIM process, and (6) technology. These performance metrics were identified through literature review, interviews and an overview of raw project data. Collected raw project data includes project BEPs, daily timesheets, ACONEX data and human resources table. Second research sub-question, which was "*What are the performance metrics required for evaluating the BIM performance based on big data from construction?*", was focusing on determining the data parameters which can be used while analyzing the project data based on identified performance metrics. Eleven data parameters were identified through interviews with the main contractor firm and investigation of the raw project data: (1) Employee name, (2) discipline, (3) task classification, (4) building name, (5) hours spent, (6) employee total cost, (7) drawing revision number, (8) drawing status, (9) task brief description and (10) date modified and (11) revision date. Proposed evaluation framework is developed with combination of these identified performance metrics and data parameters.

Suggested framework is tested in a case project. Case project was composed of two projects with similar characteristics, and the construction was carried out by the same main contractor. Construction big data used in this study is from the BIM department of a main contractor firm. Analysis of the raw project data can be grouped under four main categories: (1) revision and approved drawing information-based analysis, (2) task classification-based analysis, (3) discipline-based analysis and (4) BEP-based performance analysis. Collected project big data was analyzed based on identified performance metrics. During these analyses, the project raw data were filtered and examined with help of eleven identified data parameters. For each performance metric, data types and parameters to be used during the analysis were determined. For example, "time spent based on discipline" metric is analyzed based on daily timesheet data by using hours spent, discipline, employee name and building name parameters, while "impact of out-of-scope tasks on employee cost" metric is analyzed based on daily timesheet and human resources data by using hours spent, employee total cost, employee name, task classification and building name parameters. On the other hand, "Average revision number required for drawings to be approved" metric is analyzed based on ACONEX data with help of revision number, status, discipline and building name data parameters. Alongside with the data analysis, follow-up interviews with the main contractor were conducted to check whether the analysis results were in line with the main contractor's project experience. Table 5.1. shows which of the identified data parameters are used during the data analysis and which parameters could not be used during the analysis. Three of the identified parameters, which are revision date, date modified and task brief description, could not be used for data analyses. Task brief description parameter could not be used since employees used many different task brief descriptions for the works that could be defined under the same generalized task brief description, which made filtering and categorization based on this parameter very complex and not accurate. On the other hand, average approval durations for drawings can be calculated based on their revision numbers were possible based on the ACONEX data by using the "revision date" and "date modified" data parameters. The main reason why this analysis was not included in this thesis is that interviews with the main contractor firm revealed that data for these parameters are manipulated and not reflecting the real-life situation, for example some project participants deliberately delaying the approval or inspection of drawings because of contractual problems and interests. Therefore, although it was possible to calculate the average approval durations, this analysis was excluded from the study, since the results would lead to inaccurate conclusions.

Table 5.1. Table showing identified data parameters and their usage in data analysis.

Data Parameter	Data type in which identified parameter can be used for analysis	Parameter was used during the analysis of data based on identified metrics
Employee name	Daily timesheet data, Human resources data	Yes
Discipline	Daily timesheet data, ACONEX data	Yes
Task classification	Daily timesheet data	Yes
Building name	Daily timesheet data, ACONEX data	Yes
Hours spent	Daily timesheet data	Yes
Employee total cost	Human resources data	Yes
Drawing revision number	ACONEX data	Yes
Drawing status	ACONEX data	Yes
Task brief description	Daily timesheet data	No (Non-standard data entry methods)
Date modified	ACONEX data	No (Inaccurate and misleading data entry)
Revision date	ACONEX data	

Findings of the data analysis and verification interviews indicate that subcontractors' BIM incompetency, assignment of additional roles and responsibilities to the main contractor other than the ones specified in the contract, and lack of BIM coordination between drawings and models from different disciplines were the main factors that negatively impacted the BIM performance in the case project. These factors resulted in out of scope tasks which in return negatively affected the projects' cost and time performance. Interviews revealed that employees' and stakeholders' resistance to change and subcontractors' (especially MEP subcontractor and landscape subcontractor) inability to fulfill their roles and responsibilities, due to their BIM incompetency and their refusal to accept this situation, were the two most important barriers of BIM implementation that negatively impacted the BIM performance in the case study. Performed data analyses and data from the interviews indicate that the implementation of a detailed BEP, enhanced communication and collaboration, and improved information flow and information exchange are the most important benefits of BIM that improved the BIM performance in the case project. Table 5.2. shows the summary of identified performance metrics, the data parameters and data types used in the analysis of each metric and the analysis results for them.

Table 5.2. Table showing the summary of identified performance metrics, data parameters and data analysis results.

	Identified Performance Metrics	Data Type Used for Analysis	Data Parameters Used for Analysis	Performance Analysis Results		Verification Interview Results
				A2A3 Plot	A04 Plot	
Time	Time spent based on discipline	Daily timesheets	Discipline, building name, hours spent	Architectural - ID, MEP and Architectural - Landscape disciplines identified as having performance problems.	Architectural - ID, Architectural - Landscape disciplines identified as having performance problems. MEP discipline results did not indicate any performance problems unlike the situation in the A2A3 plot.	Architectural discipline in general, especially Architectural - ID and Architectural - Landscape disciplines, had performance problems on both plots as identified from the results of the data analysis.
	Time spent based on task classification	Daily timesheets	Task classification, discipline, building name, hours spent, employee name	%42,40 of total time spent for actual creation of shop drawings (main contractor's BIM department's main task), %46,91 of total time spent for modeling, coordination,complementary works, model submissions and reviews and meeting attendances. Remaining %9,23 spent on out of scope tasks.		
				Several employees specifically assigned for out of scope tasks on both A2A3 and A04 plots.		
Out of Scope Tasks	Ratio of time spent on out of scope tasks to overall time spent	Daily timesheets	Task classification, discipline, building name, hours spent.	4030 hours spent for out of scope tasks on A2A3 plot, corresponding to **%12,13** of total time spent on that plot. More than %50 of the time spent on **Architectural-Landscape**, **Architectural-ID** and **MEP** disciplines spent for out of scope tasks.	976 hours spent for out of scope tasks on A04 plot, corresponding to %4,64 of total time spent on that plot. More than %50 of the time spent on **Architectural-Landscape** and **Architectural-ID** disciplines spent for out of scope tasks.	MEP discipline had performance problems on both project plots. Based on data analysis results, MEP discipline on A2A3 plot identified as having performance problems while A04 plot did not show any performance problems. Reason of the wrong conclusion for A04's MEP discipline is the data entered for that discipline does not reflect the real situation.
	Impact of out of scope tasks on employee cost	Daily timesheets, human resources table	Task classification, discipline, building name, hours spent, employee total cost, employee name	Out of scope tasks impacted project performance negatively in terms of cost and time. Calculated employee cost of out of scope tasks is 398355.71$, which corresponds to **%12.60** of total employee cost.		
Drawing Revision Numbers	Average approval duration for each revision number	ACONEX data	Revision number, building name, discipline, revision status, date modified, revision date	This analysis is excluded from the thesis, since "date modified" and "revision date" paremeters, parameters that form the basis of this analysis, are manipulated in different ways by project participants due to contractual issues and interests. This manipulation in data, results in inaccurate and misleading results.		-
	Average revision number required for drawings to be approved for each discipline	ACONEX data	Revision number, building name, discipline, revision status	**Structural Discipline**		Structural discipline had performance problems on both project plots. Data analysis results were sufficient to identify lower performance on A04 plot, but at the same time results were not sufficient to identify problems on A2A3 plot for this specific discipline.
				Significantly lower approved drawing number (2743) and average revision number (1,4541), indicating **higher performance** compared to A04 plot.	Significantly higher approved drawing number (5038) and average revision number (1,7914), indicating **lower performance** compared to A2A3 plot.	
				MEP Discipline		
				No significant difference between project plots in terms of average revision number and approved drawing numbers.		
				Architectural Discipline		
				Significantly lower average revision number (2,1240) compared to A04 plot	Significantly higher average revision number (2,3758) compared to A2A3 plot.	
Organization & People	Implementation of BEP	Project BEPs, Interviews	-	Both project plots have their BEPs defined and implemented from the beginning of the project. A04 plot's BEP is more detailed in some parts, e.g., clash detection part, which is expected to result in better performance on A04 plot. **(Positive impact on performance)**		Detailed and well implemented BEP is a must to achieve best performance in a BIM project. BEP implementation in this project had a major positive impact on performance.
	Roles, responsibilities and goals identified in contract	Project BEPs, Interviews	-	Roles and responsibilities of the project participants and goals of the project are clearly identified in both project BEPs. This should eliminate any confusions between different project participants and therefore improve the performance. **(Expected positive impact on performance)**		The top management has assigned additional roles and responsibilities apart from the defined roles and responsibilities and have not reflected them in the contract, which resulted in scope creep for main contractor and increased overall time and cost of the project, therefore **impacted performance negatively.**

(cont. on next page)

Table 5.2. (cont.)

Organization & People	People's resistance to change	Interviews	-	On both project plots, various employees from the subcontractors and lead designer firms resisted to admit their incompetency and blamed BIM for the problems, which increased the time spent for solving the encountered problems. **(Major negative impact on performance)**		-
	Subcontractor's BIM competency	Interviews	-	Competency problems encountered in Landscape, MEP and interior design subcontractors. **(Negative impact on performance)**	Competency problems encountered in Landscape and interior design subcontractors. **(Negative impact on performance)**	-
BIM Process	Variety of communication methods and effective use of them	Project BEPs	-	Wide range of communation methods (including identification of formal and informal communication tools, identification of design and coordination meeting methods and frequency of these meetings, workshops and Q&A platforms) are identified and their usage is heavily promoted and made mandatory on both project BEPs. **(Positive impact on performance)**		-
	Effective BIM coordination between stakeholders	Project BEPs, Interviews	-	Means of coordination are identified and promoted in project BEP. Significant coordination problems between interior design firm and lead designer firm during the project. **(Major negative impact on performance)**	Means of coordination are identified and promoted in project BEP. No significant coordination problems between stakeholders during the project.	-
	Effective clash detection	Project BEPs	-	Clash detection processes are identified generally, but detail level is lower compared to A04 plot. **(Lower performance compared to A04 plot)**	Clash detection processes are identified, detail level is significantly higher compared to A2A3 plot. **(Higher performance compared to A2A3 plot)**	Low level of clash detection definition combined with coordination problems resulted in more clash problems on A2A3 plot.
	Effective quality control	Project BEPs	-	Quality control processes and measurements are identified in detail in project BEPs. **(Positive impact on performance)**		Although compliance with quality control processes positively affects project performance, in some cases serious problems and delays have been experienced as a result of non-compliance.
	Presence of construction scheduling and sequencing	Project BEPs	-	Construction scheduling and sequencing workflows are identified in detail in project BEPs and implemented in project. **(Positive impact on performance)**		-
	Properly defined information exchange methods	Project BEPs	-	Information exchange platforms and methods are identified in detail for both formal and informal submissions. **(Positive impact on performance)**		-
	Effective usage of BIM model for both drawing and modeling processes	Project BEPs	-	BIM usage is mandated for both modeling and drawing production processes. Generating drawings directly from the model as mandated in BEPs should prevent incompatibilities between drawings and models and ensured faster updates for design changes. **(Expected positive impact on performance)**		Effective usage of BIM model for both drawing production and modelling processes increased the BIM performance when applied properly, but when applied poorly or not applied, it disrupted the quality control process and negatively affected the BIM performance.
	Design changes	Interviews	-	Major and continious design changes in both architectural, structural and MEP design. **(Major negative impact on performance)**	Significantly lower amount of design changes in both architectural, structural and MEP design. **(Minor negative impact on performance)**	-
Technology	Technological infrastructure (Hardware&software)	Project BEPs, Interviews	-	Technological infrastructure with required hardware and software identified in detail in project BEPs and installed by the main contractor for all project stakeholders. Common technological infrastructure and single source of truth provided by BIM. **(Major positive impact on performance)**		-

Findings show that BIM performance can be evaluated based on big data from construction, with utilization of identified performance metrics and data parameters based on the developed evaluation framework. Collected project big data is analyzed mainly from the cost and time perspective based on the identified metrics and data parameters. Based on analysis results and verification interviews, it has been seen that these analyzes, which are mainly made from the perspective of time and cost, are sufficient in terms of comparing BIM performance between two project plots and detecting performance problems and mainly gave accurate results. While data analysis based on the developed framework is proved to be sufficient to evaluate BIM performance and identify performance problems, there was one case, MEP performance evaluation for the A04 plot, in which analysis based on the framework was not yielding correct results. The reason that the proposed framework is not sufficient for performance analysis in the specified situation is that the data used in the analysis were not entered in a way that reflects the actual situation. This situation pointed out to the importance of entering the data correctly preferably according to the standards predefined by the project team. Naturally, data should be entered correctly in order to yield accurate results from the analyzes based on that data.

5.1. Recommendation for Future Studies

Suggested approach in this study is specifically tailored to evaluate the BIM performance based on construction big data. Future work should focus on testing the proposed framework in larger number of studies from different companies and validate the applicability of the framework on wider scale. Developed framework might also serve as a foundation for a future benchmarking system. Future work should focus on improving the framework by refining performance metrics and establishing a database of BIM big data, alongside with performance evaluation results based on improved framework. By this way, companies will have a chance to not only measure their performance but also find the opportunity to benchmark their performance against the other project data in the database. Future work should also focus on employing techniques based on Artificial Intelligence (AI) since these methods are more suitable for big data compared to the traditional ones. BIM big data, such as data used in this study, has a potential to be used in real-time project performance assessment and utilizing AI techniques such as Machine Leaning (ML), which uses algorithms to learn from the data and make decisions based on observed patterns, may provide automated and improved real-time monitoring of project performance.

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APPENDIX A

BIM Model Audit Checklist for Quality Control

Employer:	Client Rep:	Project Manager:	CREATED BY		DATE	
			REVIEWED BY		DATE	
			APPROVED BY		DATE	
Design Consultant:	Main Contractor:		File name: **BIM EXECUTION PLAN - ANNEX 2 : MODEL AUDIT CHECKLIST**			

GENERAL				
Items to verify		**Evaluation**		**Remark**
		Bad / No	Good / Yes	
		Rejected	Accepted	
General	Number of models			
	Software used (name, version)			
	Software in english version			
	Naming quality			
	All file size < 300MB			
	Detached from central (Y/N)and retain workset			
	All Autocad attached files provided			

Figure A.1. Model Audit checklist to be followed during the quality control process of General BIM models.

Employer:	Client Rep:	Project Manager:	CREATED BY		DATE	
			REVIEWED BY		DATE	
			APPROVED BY		DATE	
Design Consultant:	Main Contractor:		File name: **BIM EXECUTION PLAN - ANNEX 2 : MODEL AUDIT CHECKLIST**			

ARCHITECTURAL MODEL					
Items to verify			**Evaluation**		**Remark**
			Bad / No	Good / Yes	
			Rejected	Accepted	
General		**Metric system (precise unit: mm, cm, m)**			
		All items in English			
		View organization (project browser)			
		Project information			
		Project base point			
		All links unloaded			
		Purged (Y/N)			
		Detail level			
Accuracy		Number of warnings			
		Wall to slab connection quality			
		Beam to slab joint quality			
Workset		Utilization of Worksets (Y/N)			
		Workset usageas defined in BIM implementation plan			
Level/grid		Naming quality			
		Reference SSL (structural slab level) only			
Project Material		Detail level of graphic presentation			
		Purged all unused materials			
Opening / Reservation		Utilization for slab (Y/N)			
		Utilization for wall (Y/N)			
Family	**General**	Utilization of proper family category for each design element			

Figure A.2. Model Audit checklist to be followed during the quality control process of Architectural BIM models.

Employer:	Client Rep:	Project Manager:	CREATED BY		DATE	
			REVIEWED BY		DATE	
			APPROVED BY		DATE	
Design Consultant:	Main Contractor:		File name: **BIM EXECUTION PLAN - ANNEX 2 : MODEL AUDIT CHECKLIST**			

STRUCTURAL MODEL

Items to verify			Evaluation		Remark
			Bad / No	Good / Yes	
			Rejected	Accepted	
General		**Metric system (precise unit: mm, cm, m)**			
		All items in English			
		View organization (project browser)			
		Project information			
		Project base point			
		All links unloaded			
		Purged (Y/N)			
		Detail level			
Accuracy		Number of warnings			
		Wall to slab connection quality			
		Beam to slab joint quality			
Workset		Utilization of Worksets (Y/N)			
		Workset usageas defined in BIM			
Level/grid		Naming quality			
		Reference SSL (structural slab level) only			
Project Material		Detail level of graphic presentation			
		Purged all unused materials			
Opening / Reservation		Utilization for slab (Y/N)			
		Utilization for wall (Y/N)			
Family	**General**	Utilization of proper family category for each de			

Figure A.3. Model Audit checklist to be followed during the quality control process of Structural BIM models.

Employer:	Client Rep:	Project Manager:	CREATED BY		DATE	
			REVIEWED BY		DATE	
			APPROVED BY		DATE	
Design Consultant:	Main Contractor:		File name: **BIM EXECUTION PLAN - ANNEX 2 : MODEL AUDIT CHECKLIST**			

MEP MODEL

Items to verify			Evaluation		Remark
			Bad / No	Good / Yes	
			Rejected	Accepted	
General		**Metric system (precise unit: mm, cm, m)**			
		All items in English			
		View organization (project browser)			
		Project information			
		Project base point			
		All links unloaded			
		Purged (Y/N)			
		Detail level			
Accuracy		Number of warnings			
		Wall to slab connection quality			
		Beam to slab joint quality			
Workset		Utilization of Worksets (Y/N)			
		Workset usageas defined in BIM implementation plan			
Level/grid		Naming quality			
		Reference SSL (structural slab level) only			
Project Material		Detail level of graphic presentation			
		Purged all unused materials			
Space M.E.P.		Utilization (Y/N)			
		Use of Space naming utility (Y/N)			
System Browser		Utilization (Y/N)			
		Assigned to Mechanical (Y/N)			
		Assigned to Electrical (Y/N)			
		Assigned to Plumbing (Y/N)			
		Naming quality			
Family	**General**	Utilization of proper family category for Ducts, Fittings, Accessories			
		Use of hosted family to face			

Figure A.4. Model Audit checklist to be followed during the quality control process of MEP BIM models.