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İSTANBUL KÜLTÜR UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

EVALUATING BIM'S IMPACT ON PROJECT PERFORMANCE IN THE AEC INDUSTRY OF THE MENA REGION

Masters of Science Thesis

Migsid Husam Abdulameer MNAEDAH

2100000707

Department: Industrial Engineering

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Migsid Husam Abdulameer MNEADAH

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

BIM	Building Information Modeling
PMBOK	Project Management Body of Knowledge
AEC	Architecture, Engineering, and Construction
MIDP	Master Information Delivery Plan
TIDP	Task Information Delivery Plan
OIR	Organizational Information Requirements
AIR	Asset Information Requirements
PIR	Project Information Requirements
EIR	Exchange Information Requirements
BEP	BIM Execution Plan
CDE	Common Data Environment
IPD	Integrated Project Delivery
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
VR	Virtual Reality
AR	Augmented Reality
KPI	Key Performance Indicator
BPMN	Business Process Model and Notation
CAD	Computer-Aided Design
3D	Three-Dimensional

ÖZET

YAPI BİLGİ MODELLEME (BIM) YAKLAŞIMININ MENA BÖLGESİ AEC SEKTÖRÜ PROJE PERFORMANSI ÜZERİNDEKİ ETKİSİNİN DEĞERLENDİRİLMESİ

Migsid Husam Abdulameer Mnaedah

İnşaat sektörü genellikle proje gecikmeleri, maliyet aşımı ve kaynak kıtlığı gibi zorluklarla karşı karşıyadır. Bu sorunlar, geleneksel yaklaşımlarda veri koordinasyonunu ve projeye dahil olan paydaşlar arasındaki iletişimi yöneterek çözülebilir. Ancak inşaat alanı karmaşıklık ve çok sayıda faaliyetle karakterize edildiğinden, bu prosedürlerin uygulanması karar vericiler için bir engel haline gelir. Bu araştırmanın amacı bu sınırlamayı çürütmek ve yenilikçi bilgi yönetimi tekniklerinin amaçlanan uygulamasını göstermektir. Bina bilgi modelleme (BIM) teknolojisinin çeşitli yönlerinin proje performans alanlarını etkileme derecesini ve proje performans alanlarının benimsenme derecesini ve BIM yönlerinin uygulama düzeylerini inceler. Bu çalışma sırasında, performans alanlarının ve BIM yönlerinin benimsenme düzeyini inceledikten ve aralarındaki ilişkiyi incelemek için korelasyon analizi yaptıktan sonra, BIM yönlerinin proje performans alanları üzerindeki etkisini hesaplamak için çoklu regresyon analizi yapılmıştır. Çalışma, Orta Doğu ve Kuzey Afrika (MENA) bölgesinde 153 profesyonelin katıldığı bir anket yürütülmüş, ve bu anket, bina bilgi modellemesinin (BIM) benimsenmesinde önemli coğrafi farklılıkları ortaya koymuş ve ekip deneyimi, karmaşıklık ve BIM uygulama seviyeleri arasındaki ilişkiyi vurgulamıştır. BIM entegrasyonunun zorluklar sunduğu alanları belirlemenin yanı sıra, ordinal lojistik regresyon modelleri, BIM'in bilgi yönetimi ve entegrasyonunun paydaş memnuniyeti ve ekip işbirliği gibi performans alanları üzerindeki olumlu etkilerini daha da açıklığa kavuşturmaktadır. BIM araçlarının performans alanına entegre edilmesi, hedeflenen çözümlerin geliştirilmesi, süreçlerin analizi, operasyonel boşlukların belirlenmesi ve ayrıntılı modellerin oluşturulması, projelerin başarısı ve Mimarlık, Mühendislik ve İnşaat (AEC) alanlarındaki profesyoneller için karar alma süreçlerinin optimizasyonu üzerinde önemli bir etkiye sahiptir.

ABSTRACT

EVALUATING BIM'S IMPACT ON PROJECT PERFORMANCE IN THE AEC INDUSTRY OF THE MENA REGION

Migsid Husam Abdulameer Mnaedah

The construction industry typically faces challenges, including project delays, cost overruns, and resource shortages. These problems can be solved by managing data coordination in traditional approaches and communication between stakeholders involved in the project. However since the field of construction is characterized by complexity and a large number of activities, the implementation of these procedures becomes an obstacle for the decision-makers. The goal of this investigation is to refute this limitation and demonstrate the intended implementation of innovative information management techniques. It examines the degree to which various aspects of building information modeling (BIM) technology impact project performance domains, as well as the extent to which project performance domains are adopted and the implementation levels of BIM aspects. During this study, after examining the adoption level of performance domains and BIM aspects and performing correlation analysis to examine the relationship between them, multiple regression analysis was performed to calculate the impact of BIM aspects on project performance domains. The study conducted a survey of 153 professionals in the Middle East and North Africa (MENA) region, which revealed substantial geographical disparities in the adoption of building information modeling (BIM) and underscored the correlation between team experience, complexity, and BIM implementation levels. In addition to identifying domains where BIM integration presents challenges, ordinal logistic regression models further elucidate the positive impacts of BIM's information management and integration on performance domains such as stakeholder satisfaction and team collaboration. The integration of BIM aspects into the performance domain, the development of targeted solutions, the analysis of process paths, the identification of operational voids, and the creation of detailed models have a substantial impact on the success of projects and the optimization of decision-making processes for professionals in the fields of Architecture, Engineering, and Construction (AEC).

1. INTRODUCTION

1.1. Background information

1.1.1. Impact of Communication Gaps on Project Management

The absence of communication and coordination between partners is one of the key causes of the project's delay (Zidane & Andersen, 2017). Furthermore, Gamil and Abdul Rahman (2017) highlight how inefficient communication can lead to cost overruns in the construction industry. Consequently, some communications and coordination management procedures, such as data production, collection, dissemination, and retrieval, play a significant part in the project's success (Senaratne & Ruwanpura, 2015). Even so, when many jobs are outsourced to several contractors, these procedures become more complicated (Yap et al., 2021). Inadequate planning, unrealistic schedules, lack of standardization, and poor cost estimating can lead to cost and time overruns (Zahmak et al., 2020). These issues are common in the worldwide construction industry, but their importance varies by cultural values and practices. These issues should be addressed quickly, starting with planning and continuing with the execution and management stages (Durdyev et al., 2012).

According to Kazaz et al. (2012), these considerations indicate that project participants do not create real-time planning and estimations and that owners are not using expert project management services and consultants. Many procedures, techniques, and tools have been developed since project management became a field of study in the mid-20th century. They cover the entire project lifecycle and have improved project management efficiency and effectiveness, leading to increased project success rates (Varajão, 2016). In today's continuously changing business environment, software projects necessitate using software engineering concepts to improve project management effectiveness abilities to achieve a successful project outcome (Barghoth et al., 2020).

1.1.2. Implementation of Information Management in Construction

Complicated assets involve implementing new information management techniques, tools, and technology (Khudhai et al., 2021). Moreover, these strategies positively influence the Architectural Engineering and Construction (AEC) sector to ensure long-term efficiency

(Arthur et al., 2018). Building information modeling (BIM) will grow in significance for contractors because it supports cooperation, enhances design quality by enabling 3D visualization, and allows the exchange of design, construction, and maintenance information throughout a building's lifecycle. (Gerges et al., 2017), also stated that the architectural, engineering, and construction (AEC) organizations in the Middle East have adopted BIM, despite the low utilization rate in local projects, it is clear that firms are becoming more aware of the growing domestic demand for BIM contracts.

BIM technology is extensively used in construction as the future direction of digitalization, informatization, and intellectualization, which is considered the second industrial revolution of construction. The first revolution is the use of CAD technology (Cheng et al., 2019). (Building Information Modeling, n.d.) defined BIM as "an intelligent 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure". BIM is a phrase used to describe a set of parametric tools and techniques for creating and managing a multi-dimensional database of information about a building's design, construction, and operations (National Institute of Building Science, 2007). According to Hergunsel (2011), BIM is a three-dimensional digital representation of a building and its inherent properties. It is composed of intelligent construction elements, each of which contains data properties and parametric rules.

According to the virtualization of the construction process, it is possible and practical to use BIM for quality management and documentation efficiency (Chen & Luo, 2014). According to Yuqi and Jiajia (2018), BIM can help managers make more informed scientific decisions. It also improves existing communication processes, promotes collaboration, and enables cross-domain interoperability (Al-Ashmori et al., 2020). With BIM, profitability is increased, costs are reduced, and the project is finished on schedule (Mesároš & Mandičák, 2017). Furthermore, it employs the object-oriented paradigm to streamline the management of building life-cycle information (Charehzehi et al., 2017; Xu et al., 2014) and incorporates a new methodology for controlling and managing conflicts (Charehzehi et al., 2017). Besides that, it may be utilized as a data supplier and a collaborative platform for construction-project risk management (Sun et al., 2015).

The most often used BIM software are REVIT (modeling), Navisworks (construction virtualization), Green Building Studio (sustainability software), and Bentley Facilities (facility management).

1.1.3. Adapting Project Management for Modern Construction Challenges

Project management processes and procedures are the foundation of management systems, allowing for adaptation to dynamic environmental alterations and ensuring the achievement of organizational goals through the use of structured and efficient frameworks (Dianov & Isroilov, 2022). An appropriate standard is suitable for construction project management because it identifies the set of project objectives, improves organizational processes by focusing on human resources, reduces the costs and time required to manage a new effort, achieves consensus, and establishes a common language among stakeholders (Faraji, 2021). In the past ten years, academic and professional revolutions have reshaped all areas of technology (Faraji et al., 2022). BIM and digital construction have revolutionized industries because traditional management techniques and tools are not capable of advancing increasingly complex projects. The Project Management Institute (PMI) responded to this difficulty by revising the outdated approach in the PMI (2021). This version addresses core industry challenges by moving the emphasis from knowledge areas to project performance domains. According to Faraji et al. (2022), new project management concepts and performance domains can be applied to various construction projects. Aladag et al. (2016) emphasize the economic advantages of BIM as an appropriate innovative information management system, including cost reductions and profitability gains, technology breakthroughs that incorporate BIM into complex projects, and improved industry cooperation and coordination. On the other hand, cultural barriers, environmental objectives, insufficient legal frameworks, and varying stakeholder awareness highlight the continued need for BIM as a solution.

1.2. Research Aims:

This study aims to comprehensively develop the following:

1. Evaluate the adoption and contribution of project performance domains within the (AEC) industry in the Middle East and North Africa (MENA).

2. Investigate the impact of Building Information Modelling (BIM) on the project performance domains of the (AEC) industry in the (MENA) region.

1.3. Research Objectives:

1. Determine the key factors that influence performance domains in the AEC industry in the MENA region.
2. Analyze the effect of BIM on performance domains of (AEC) industry in the (MENA) region.

1.4. Research Questions

1- What are the key factors affecting AEC performance domains in (MENA) region, and their impact on outcomes?

2- What is the role of BIM in improving AEC project management in (MENA) region?

1.5. Research Hypotheses

1.5.1. Stakeholders Performance Domain

$H_{0.1a}$, $H_{0.2a}$, $H_{0.3a}$: BIM's information management, technical, and integration variables do not enhance the stakeholder performance domain.

1.5.2. Team Performance Domain

$H_{0.1b}$, $H_{0.2b}$, $H_{0.3b}$: BIM's information management, technical, and integration variables do not enhance the Team Performance Domain.

1.5.3. Development Approach and Lifecycle Performance Domain

$H_{0.1c}$, $H_{0.2c}$, $H_{0.3c}$: BIM's information management, technical, and integration variables do not enhance the Development Approach and Lifecycle Performance Domain.

1.5.4. Planning Performance Domain

$H_{0.1d}$, $H_{0.2d}$, $H_{0.3d}$: BIM's information management, technical, and integration variables do not enhance the Planning Performance Domain..

1.5.5. Project Work Performance Domain

$H_{0.1e}$, $H_{0.2e}$, $H_{0.3e}$: BIM's information management, technical, and integration variables do not enhance the Project Work Performance Domain.

1.5.6. Delivery Performance Domain

$H_{0.1f}$, $H_{0.2f}$, $H_{0.3f}$: BIM's information management, technical, and integration variables do not enhance the Delivery Performance Domain.

1.5.7. Measurement Performance Domain

$H_{0.1g}$, $H_{0.2g}$, $H_{0.3g}$: BIM's information management, technical, and integration variables do not enhance the Measurement Performance Domain.

1.5.8. Uncertainty Performance Domain

$H_{0.1h}$, $H_{0.2h}$, $H_{0.3h}$: BIM's information management, technical, and integration variables do not enhance the Uncertainty Performance Domain.

1.6. Variables

1.6.1. Independent Variables:

1.6.1.1. BIM information management

- BIM Information Requirements Management (BIRM)
  Evaluate how effectively the BIM process manages and integrates the Organizational (OIR), Asset (AIR), Project (PIR), and Exchange (EIR) Information Requirements throughout the project lifecycle.
- Information Delivery Efficiency (BIDE)
  Assesses the quality of information management practices at both the overall project level (Master Information Delivery Plan, MIDP) and individual task level (Task Information Delivery Plan, TIDP).

1.6.1.2. BIM Technical execution

- BIM Analysis and Optimization Level (BAOL)
  Assesses the effectiveness and integration of energy analysis and clash detection in BIM projects.

1.6.1.3. BIM Integration Variables

- BIM Cost and Material Management (BCMM)
  Evaluates the effectiveness of BIM in the context of material procurement and cost control.
- BIM Quality Control and Validation (BQCV)
  Measures the level of adherence to quality standards and regulations within construction projects using BIM.
- BIM Collaboration and Communication (BCC)
  Evaluate the efficacy and integration of BIM in facilitating communication and collaboration on construction projects.
- BIM Training and Competence (BTC)
  Indicates the proficiency of the workforce in effectively implementing BIM technologies and the level of BIM training received.

1.6.2. Dependent Variables:

- Stakeholders Performance Domain.
- Team Performance Domain
- Development approach and lifecycle Performance Domain
- Planning Performance Domain
- Project work Performance Domain
- Delivery Performance Domain
- Measurement Performance Domain
- Uncertainty Performance Domain

1.6.3. Control Variables:

- Organizational characteristics
- Project characteristics

1.7. Research Significance

The importance of the research lies in its contribution to understanding the impact of BIM aspects on performance areas in Middle East and North Africa projects, where BIM adoption is heterogeneous and under development (Hajj et al., 2021). Moreover, the region faces unique challenges in construction projects. The study helps bridge the gap between BIM-enabled users and construction project management practitioners within a broader framework, enabling researchers to understand which aspects of BIM have an impact on performance areas in the project. Policymakers and contractors can use this empirical evidence to make decisions about adopting BIM as a tool to improve and regulate project performance in the region. In addition, reviewing the tools and benefits of BIM through a literature review may provide a case for convincing stakeholders and project managers to adopt it in their projects.

1.8. Scope and structure of thesis (Essay map)

1.8.1. Scope

The focus of the study in this thesis is on how BIM affects different project performance areas in the AEC sector, more especially in the MENA region. The purpose of the study is to comprehend the impact of BIM implementation on the domains of Stakeholder, Team, Development Approach & Life Cycle, Planning, Project Work, Delivery, Measurement, and Uncertainty.

1.8.2. Structure

The thesis is divided into 5 major chapters to accomplish the main goals of the study and respond to the developed research questions:

- Introduction:

The way that BIM closes communication gaps in the AEC sector is examined in this part. Emphasizing the need for efficient data management, it shows how these gaps affect project delays and cost overruns. The collaborative framework of BIM is examined in this paper along with possible difficulties in the MENA region and the necessity for project management frameworks to keep up with contemporary construction issues.

- literature review:

The three primary areas covered in this section are project performance domains, building information modeling aspects. Eight domains that affect project results in the AEC industry are reviewed in the first section: stakeholder, team, development approach & life cycle, planning, project work, delivery, measurement, and uncertainty. In the second part, technical execution, information management, and collaboration and communication strategies—all of which directly affect these performance domains—are examined.

- Methodology:

This section describes the analytical approaches, data collecting strategies, and research design used to assess how BIM influences project performance domains. It comprises

  - The design of the questionnaire meant to gather quantitative information from MENA area professionals.
  - Research Data Analysis Using Principal Component Analysis (PCA) and Kaiser-Meyer-Olkin (KMO) Test
  - The use of ordinal regression analysis techniques, correlation analysis, and descriptive statistics is underlined in the analytical framework.

- Implementation and results:

This chapter contains the data analysis findings.

The following is included:

  - The results of the PCA, the research setting, the participants, and their perceptions of both the performance domains and BIM aspects.
  - The outputs from the ordinal logistic regression models for each project performance domain, emphasize the significant predictors.
  - Statistical evidence-based comparative analysis of the impact of BIM aspects on each performance domain.
  - Discussion and Comparative Analysis: This section explores the interpretation of results by comparing them to the existing literature.

- Conclusion:

This chapter presents the conclusions, addresses the research questions, and summarizes the primary findings of the study.

2. LITERATURE REVIEW

2.1. Project Performance Domains

2.1.1. Stakeholders Performance

PMBOK defines the stakeholders' performance domain as "addresses activities and functions associated with stakeholders that result in a productive working relationship with stakeholders throughout the project”. Those who have a beneficial or unfavorable influence on the project are recognized as stakeholders.

Freeman (2010) defined stakeholders as "those who can influence or be influenced by the attainment of the organization's objectives" The number of people involved in a project might range from a hundred to a million. Stakeholder types include main stakeholders, like suppliers and customers, or secondary stakeholders, such as communities and social activist organizations. The stakeholders are identified at the beginning of the project and updated throughout its lifetime. In addition, stakeholders have varying levels of interest and influence, which leads to conflict and lower construction sector efficiency. Ma et al. (2018) think that innovation, respect for habitats and culture, and increasing environmental management may be utilized to integrate conflicting stakeholder interests and enhance sustainable performance.

2.1.1.1. Stakeholder Engagement

Stakeholder engagement is defined by PMI (2021) as "the implementation of strategies and activities to enhance the productivity and involvement of stakeholders and to build relationships with them. “There are various approaches to properly engaging stakeholders.

Identify

Identifying the participating and non-participating stakeholders is a necessary stage as it is a crucial aspect of the planning stage. It is possible to identify stakeholders based on their interests, power, and orientation. The most frequent approach for identifying stakeholders in the sphere of influence (Damian et al., 2013). The major stakeholders are individuals such as suppliers, customers, and end-users; they are external organizations. The inner layer represents organizational groups such as governing bodies, PMOs, and steering committees.

The lowest layer describes the project stakeholders, such as the project manager, project management team, and project team.

Understand and Analyze

After identifying stakeholders, it is necessary to classify their demands and various aspects (expectations, influence, opinions, interests, and requirements) both within and beyond the project environment to manage them more efficiently.

Prioritize

Several projects, particularly significant construction facilities, will include numerous stakeholders. In projects with competing stakeholder requirements and expectations, it is difficult to involve all of them directly and efficiently. Managers must recognize whose objectives are prioritized and whose viewpoint carries greater weight. These deliverables are necessary to design a strategy for stakeholder involvement, collect requirements, and define the project's scope (Lin et al., 2017).

Engage

To achieve collaborative working in stakeholder engagement, the following components should be included in each engagement plan: the present profile of each stakeholder in the strategy required to attain the target profile, guidelines and metrics for monitoring and evaluating strategy effectiveness, a schedule of meetings and exchanges with various stakeholders regarding the information that must be delivered or collected during each meeting, and a communication plan outlining each stakeholder's reporting requirements and the frequency of these reports. Because these engagement components are inherent in engagement procedures, their importance should not be disregarded when analyzing what works effectively on projects (Collinge, 2020).

2.1.2. The Team Performance

The Team Performance Domain defined in PMI (2021) "addresses activities and functions associated with the people who are responsible for producing project deliverables that realize business outcomes."

2.1.2.1. Project Team Management and Leadership

According to PMBOK, Management and leadership are not synonymous; each requires a unique set of skills, traits, and responsibilities. Leadership is a method of social influence that optimizes the efforts of project teams to attain a goal or objective. On the other hand, management is the art of work performed by individuals to the satisfaction of the public, employer, and the workforce. The objectives of these activities include, among other things, establishing good processes, and coordinating and monitoring activity.

According to Wang et al. (2012), many project practitioners feel that a project's structure and management have a significant impact on the project's success. Consequently, the project manager should establish a well-organized management structure for project teams.

Management operations may be centralized or distributed, with a centralized system allocating power or authority to the organization (Martin et al., 2014). Alternatively, a project team may also self-organize, with a Servant leader functioning as a facilitator to facilitate communication, collaboration, and engagement. Sharing duties and decisions or enhancing the exchange of information is one of the new approaches to coordinating systems, since these strategies may push the performance of the project team toward fulfilling its shared purpose (Xue et al., 2021).

2.1.2.2. Vision and Responsibilities

Within the project-based enterprise Adopting BIM, methods requires a team with a clear and shared vision; nevertheless, involvement is often characterized by short meetings of unknown groups of people. According to Milivojević (2020), a Vision must be formed early in the project or before the project begins. Some new members must adapt to a new organization's procedures and understand its mission, vision, and basic values.

2.1.2.3. Project Team Culture

Manzanares et al. (2021) imply in a literature review that firm culture, leadership, and knowledge management might affect technical knowledge production. A positive company culture attracts talent, encourages engagement, and influences happiness and performance. In building projects, fostering constructive collaboration brings the team closer and unifies it. If construction project performance is to be investigated, top management must establish a collaborative atmosphere.

2.1.3. Development Approach and Lifecycle Performance

The Development Approach and Life-Cycle Performance Domain “addresses activities and functions associated with the development approach, cadence, and life cycle phases of the project.”

This valuable perspective is one way to introduce more agile concepts into the construction industry. It is tailored to the construction industry because it emphasizes the role of the operation phase as the final ring in the project's value chain and provides more support for the acceleration of phases and meeting expectations (Faraji et al., 2022).

2.1.3.1. Delivery Cadence

There is a possibility that certain projects will only entail a Single delivery, while others can involve Multiple or Periodic deliveries. As the cadence of delivery simply relates to the timing and frequency of project delivery, the activities must maintain the proper cadence.

2.1.3.2. Development Approaches

The Project Management Institute (PMI) has developed a new strategy that does not favor the development and life cycle approach above others. There is a need to design all projects according to their nature, where there are aspects to be taken into account while picking a development strategy. These variables may be classified as product, service, or result categories, as well as organization. PMI has created a new approach that does not prioritize development and life cycle methods above others. All projects must be designed depending on their nature, and there are factors to consider while choosing a development plan. These factors are categorized as product, service, or outcome, as well as organization. The approach used for development should match the characteristics of the outcomes. It is an integral component of the project value delivery system since it provides a method for delivering value from the project's beginning through its closure.

2.1.3.3. Common Development Approaches in Project Management

There are several different development methodologies, including predictive, hybrid, and adaptive. In PMI (2021) , the predictive approach was underlined. It is also known as a waterfall. It entails doing as much planning as possible before starting a project. Defining, collecting, and evaluating project requirements early on is advantageous. This method of development decreases project uncertainty and permits early planning. When a project is uncertain, it is essential to use an adaptive strategy (Lalmia et al., 2021). Hybrid development is the third most prevalent. It is the distinction between predictive and adaptive strategies that capitalize on their strengths and eliminate their weaknesses. It is more adaptable than predictive but has some predictive characteristics. When deliverables may be modularized or generated by separate project teams, the hybrid approach is suitable (Lalmia et al., 2021).

2.1.4. Planning Performance Domain

2.1.4.1. Strategic Planning:

Effective planning requires the ability to adapt, which is best accomplished through iterative methods that rely heavily on intricate interconnections. Lawrence and Scanlan (2007) argue that the iterative procedure enhances the quality of information, hence facilitating the successful execution of planned creative activities.

In addition, Salkić (2014) states that the propensity of managers to allocate resources influenced by personal biases, self-driven desires, or political tensions may be reduced by the implementation of performance criteria and strategic planning. This strategy can result in a more impartial and effective distribution of resources.

2.1.4.2. Estimating:

Dandan et al. (2019) emphasize the significance of precise cost estimates at the first stages of a project to evaluate its viability and effectively manage expenses. They highlight that the experience of both the customer and the project team greatly influences the accuracy of estimations.

2.1.4.3. Schedules

Scheduling involves the deliberate planning and coordination of actions, including their interconnectedness and resource requirements. According to Hameri and Heikkilä (2002), it is recommended to prioritize the effective allocation of time for each activity and provide a smooth progression through the sequence of essential activities. The schedules outline a detailed project plan, specifying the start and end dates for each task along with any interdependencies or constraints affecting the timeline.

Construction projects often face the challenge of limited resources, including time, financial resources, personnel, equipment, and materials. When there is a simultaneous need for project assets across many assignments, it gives rise to a competitive scenario that may lead to schedule conflicts. Moreover, the rule that governs the order in which tasks are carried out, known as precedence limits, has an impact on scheduling, particularly when paired with limitations on resources (Hartmann & Briskorn, 2022). The occurrence of these issues may result in delays to the whole undertaking if a critical activity is postponed (Dehghan & Ruwanpura, 2011).

To address these challenges, Mikulakova et al. (2010) devised an approach to effectively tackle the complicated and ever-changing aspects of scheduling in building projects. they emphasize the need for a scheduling system that is both adaptable and efficient, with the ability to update and adjust schedules in response to changing project circumstances. The findings of their research highlight the use of building information to create automated scheduling systems with adaptability for real-time modifications, which enhances the transparency and comprehensibility of building process control.

2.1.4.4. Budget

The conventional approach to determining cost flow curves is evaluating production volumes at designated intervals via the use of progress schedules, followed by the application of unit costs to these quantities for budgeting. There is an important shift within the sector towards the use of automated techniques to enhance the effectiveness and precision of financial estimation. The use of technology in the management of construction finances represents an advancement, emphasizing the need for a complete system to efficiently handle cash flows and assist in project financing (Lu et al., 2016).

In line with these advancements, professionals should depend on spreadsheets and software to estimate project cash flows, using an integrated methodology that effectively schedules expenses. This approach necessitates the development of a comprehensive project schedule that is derived from the bill of quantities (BOQ). It regards cash as an essential resource that is under the project's financial needs and timetables Cui et al. (2010).

2.1.4.5. Changes

All project stakeholders should understand the contractual and legal issues associated with contractual changes due to necessary changes that may result in delays, disputes, and increased costs. El-Adaway et al. (2016) stated that proficiency in contract terms and understanding stakeholders' rights and responsibilities are key to minimizing disputes and effectively managing time extensions, delay analysis, and payment terms in various standard contracts.

Furthermore, The Project change may come to pass for a variety of reasons, including evolving requirements, design errors, unforeseen site conditions, and various administrative factors. These factors might lead to modifications in project elements, possibly expanding the project duration. However, if such changes can be predictable in the initial phases of the project, identifying them can serve to mitigate their consequence (Padala & Maheswari, 2022).

2.1.5. Project work performance domain

2.1.5.1. Customizing approaches

A customized strategy that integrates lean, agile, and waterfall methodologies is essential for managing dynamic project characteristics and advancing the construction industry (Owais, 2022).

Methods for process improvement:

1. Lean Production Methods:

   Bajjou and Chafi (2020) highlight the efficacy of lean construction methods in eliminating non-value-adding activities, which for reinforcement processes results in a 41% increase in productivity, a 14% increase in efficiency, and a 17% reduction in cycle time. Additionally, Ju et al. (2017) discuss the benefits of Integrated Project Delivery (IPD), a critical lean construction strategy that promotes collaboration among project participants and enhances information sharing, stakeholder identification, and risk mitigation.

2. Learning Lessons Throughout Work Project:

   Eken et al. (2015) identify three essential lessons: first, the necessity of conducting thorough code analysis and selecting subcontractors with care to prevent expensive reworks; second, the utility of prudent contracting and a reserve parts store in effectively managing fluctuations in exchange rates; and third, the flexibility of contract terms in addressing the expenses associated with new materials. In the field of building project management, these insights emphasize the importance of practical movements and learning from past mistakes to improve future project planning and execution.

3. Adhering to Quality and Standards:

Meijer and Visscher (2017) emphasize the importance of enhancing quality control mechanisms and strict adherence to legal regulations by construction firms. Additionally, this serves as a precautionary measure for both the occupants and guests of these edifices.

2.1.5.2. Balancing competing constraints

Effective stakeholder engagement helps to align decision-making with the project goals and expectations of all involved parties. While some decisions require consultation, others remain under the project team's control, allowing them to make swift trade-offs. However, stakeholder conflicts significantly shape the project's cost, duration, and resource allocation, indicating that the intensity of these conflicts directly impacts these constraints (Irfan et al., 2019).

2.1.5.3. Material resources management

Physical resources, including materials, equipment, and other tangible assets, are crucial for the successful completion of project work. Material resources management for construction projects may require the implementation of the following strategies:

1. Integrated logistics system:

   Organizations typically integrate integrated logistics systems into their broader policies to ensure uniformity in handling resources across different projects. The logistics plan is modified at the project level to satisfy unique project requirements, outlining management, transportation, and resource allocation (Sundquist et al., 2017).

2. Synchronization with Project Schedule:

To guarantee the prompt accessibility of resources throughout each stage of the endeavor, it is necessary to synchronize resource management by real-time monitoring, transparent communication, and expectation establishment with the primary project schedule. Moreover, resource normalization is implemented in project scheduling to mitigate fluctuations in resource consumption throughout the implementation phase. (Cheng et al., 2016).

2.1.5.4. The Bid Process

The bidding process involves project owners requesting proposals based on identified developmental needs. Contractors are evaluated on their professionalism, adherence to deadlines, cost-effectiveness, and environmental impact to ensure optimal client value (Aliakbarlou et al., 2018). Hwang and Kim (2015) emphasize the importance of precise specifications, project scale, and clarity in bidding rules for creating effective bid documents that mitigate risks and capitalize on opportunities. Pre-bid meetings allow vendors to clarify project specifics, significantly reducing cost and schedule overruns (Lines et al., 2014). Proposals are then evaluated based on financial and performance metrics, increasingly incorporating social and environmental factors, though initial cost often remains the primary determinant (Ruparathna & Hewage, 2015).

2.1.5.5. Learning throughout the project

Periodic Review and Improvement

According to McGrath and Blike (2015), the integration of strong team-based learning and coaching results in a comprehensive range of learning outcomes. This is supported by various strategies, including organizational spread, project execution status, feedback scores from participants, and projections of return on investment. This approach efficiently enables hands-on experiences in ongoing enhancement, making a substantial contribution to the success of the project.

Knowledge Management

Projects serve as fertile grounds for knowledge acquisition, with some learnings being project-specific and others applicable across various teams or the entire organization. Kokkonen and Alin (2015) underscore the importance of practice theory and experiential learning. The findings of this study spotlight areas that have received minimal attention in existing literature, while illustrating that a practice-based approach is making notable strides in the field of construction management.

Tacit knowledge

Tacit knowledge, which encompasses expertise and talents gained through experience and is often implicit in standard operations, should be acknowledged, with systematic ways developed for capturing and disseminating this information to improve its use (Addis 2016).

2.1.6. Delivery Performance Domain

2.1.6.1. Delivery of value

Business Case Role

In Public-Private Partnerships (PPPs), especially in construction, developing a detailed business case is essential for outlining project feasibility, costs, and benefits, attracting financing, and gaining stakeholder approval. Gannon and Smith (2011) discuss how PPP project delivery influences business case development, advocating for an Outline Business Case (OBC) that reflects procurement and financing methods clearly and moves away from traditional reliance on past experiences. Their approach highlights the importance of diverse data sources in ensuring decisions are based on accurate and relevant information, which is vital for the success of PPP projects.

Project-authorizing documents

A review of the literature shows that poor quality in design documentation leads to inefficiencies in construction projects. Agbaxode et al. (2023) addressed this research gap through a meta-synthesis methodology, surveying industry professionals such as project managers and engineers. This study's findings were illuminating, highlighting major problems like delays in projects, abandonment, and increased costs, all linked directly to the inferior quality of design documentation.

2.1.6.2. Deliverables

Requirements

Yu and Shen (2013) identified significant challenges in project requirements management, including the lack of a practical framework and difficulties in interpreting and identifying requirements. Building on these challenges, Jalaei and Jrade (2015) emphasized the necessity of initiating projects with a well-prepared procedure for eliciting and documenting requirements to ensure project success. This method helps clarify client needs and reduce misunderstandings by involving stakeholders and end-users early in the process, ensuring accurate requirement identification and clarification.

Scope Definition

According to the aspect of scope improvement throughout various stages of the project, the study by Esfahani et al. (2020) involves a systematic approach to identify specific elements within the project that require detailed scope definition. Once these elements are identified, the next step is to evaluate and filter out any elements that are not essential to streamlined project delivery. This targeted improvement is crucial for navigating complex project environments and ensures that resources are allocated efficiently. This approach paves the way for developing a Work Breakdown Structure (WBS) which divides a project into manageable work packages, each characterized by a well-defined scope (Al-Kasasbeh et al. 2021)

Moving Targets of Completion

Ajmal et al. (2021) adopt a comprehensive methodology to identify and validate factors contributing to moving targets of completion in the United Arab Emirates construction industry. The results reveal five main factors impacting project scope creep: tasks/specifications, complexity/uncertainty, risk, communication, and customer requirements. The study's findings provide critical insights for project stakeholders, emphasizing the need for thorough scope management and proactive strategies to mitigate scope creep in construction projects.

2.1.6.3. Quality

Quality in construction focuses on achieving specified performance levels, particularly in meeting design conformance and minimizing defects during the construction phase, as Raouf and Al-Ghamdi (2023) note. The operational phase shifts focus to sustainability and end-user satisfaction. Quality control adjusts processes to achieve desired product quality, while quality assurance ensures that building components will perform satisfactorily in service.

Costs of Quality Compliance: Prevention, Appraisal, and Failure Costs

Garg and Misra (2021) examine the Cost of Quality (CoQ) in construction, delineating Conformance Cost (CC) and Nonconformance Cost (NCC) as part of the Overall Cost (OC) in their study of 122 projects using the Prevention-Appraisal-Failure (PAF) model. They find that effective CC implementation reduces defects and thus reduces NCC, highlighting cost savings from improved quality control. However, they note a point of diminishing returns where further increases in CC do not proportionately reduce NCC, presenting a trade-off in financial decision-making for project managers. The total cost of quality is minimized at an optimal level of defects, as demonstrated in Figure 1, by balancing the costs of conformance and non-conformance.

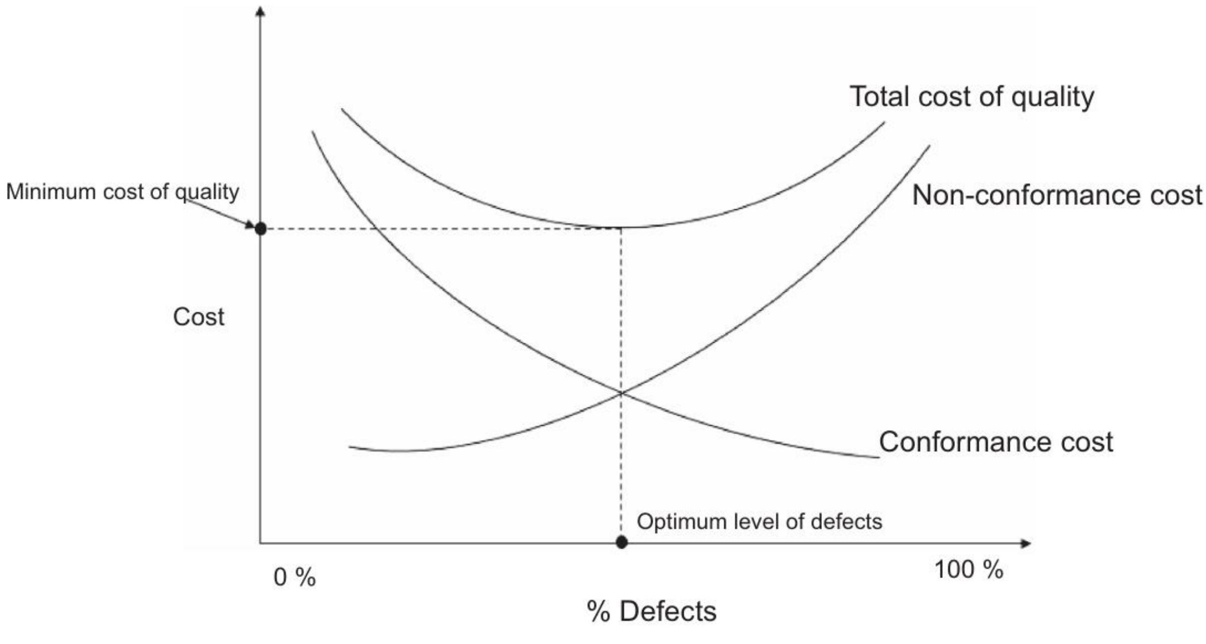
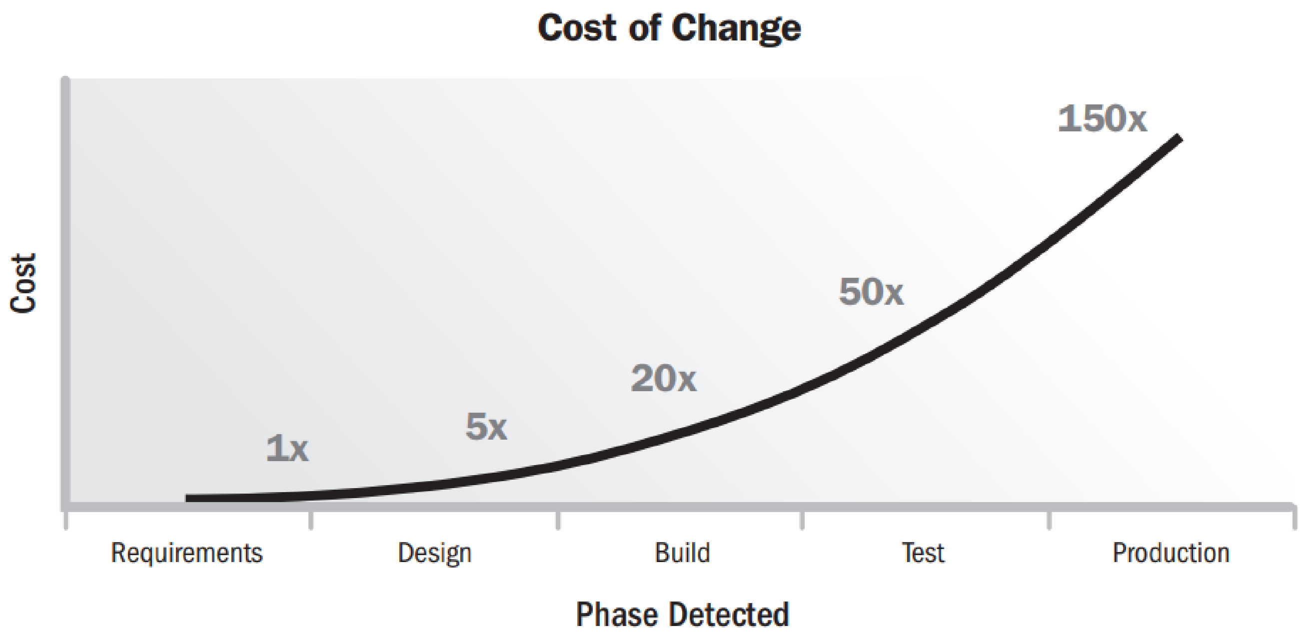


Figure 1: Traditional cost of quality curve

Cost of Change



Barry Boehm's seminal work on the cost of change in software development illustrates an exponential rise in the cost of changes across project stages from requirements to deployment . As illustrated in Figure 2, Boehm (1984) found that correcting an error in the requirements phase is significantly cheaper than post-deployment, where costs can increase up to 100 times due to the complexity and extensive rework required, including updates to documents, code, and formal change processes.

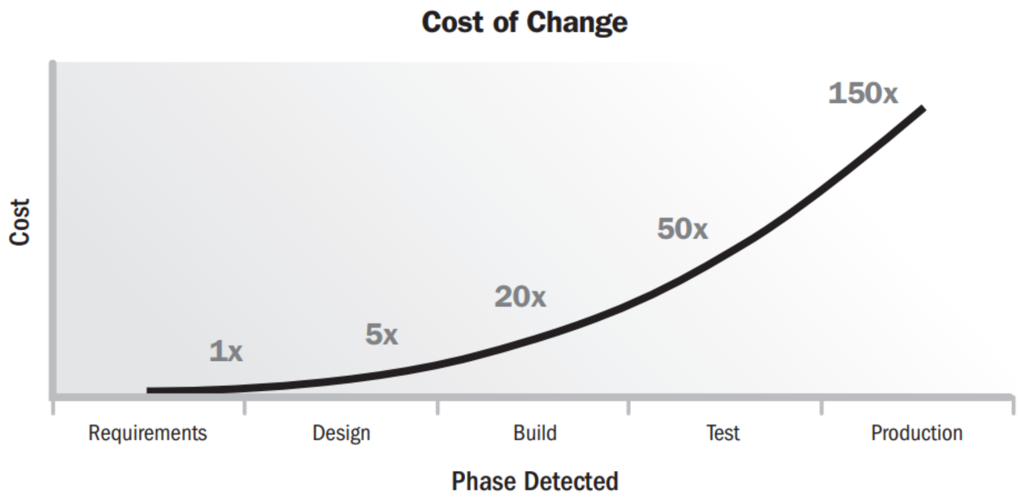


Figure 2: Boehm's Cost of Change Curve Adapted from Boehm (1984b)

Drawing on the principles, there's a parallel imperative in construction project management to minimize substantial alterations post-commencement. Thus, a meticulously orchestrated project delivery approach must prioritize rigorous initial planning, detailed design, comprehensive site assessments, and unambiguous communication (Khan et al., 2021). Furthermore, Hwang and Low (2012) reveal that companies who adopted change management practices report significant improvements in project performance, including cost savings and time efficiency, with a 73% positive response rate. This has led to fewer delays and reduced rework, showcasing the efficacy of change management in risk mitigation and a 1 to 3% enhancement in project quality, underlining its critical role in boosting overall project outcomes.

Maximizing Value Through Early Detection of Quality Issues

Luo et al. (2022) highlight the shift in construction quality management toward integrating digital technologies for defect detection and prevention, moving beyond traditional visual and manual methods. Their study advocates using advanced techniques such as computer vision and thermal testing to improve surface defect identification in materials and minimize human error through automation.

2.1.7. Measurement Performance Domain

The Measurement Performance Domain evaluates the degree to which the work done in the Delivery Performance Domain meets the metrics identified in the Planning Performance Domain.

2.1.7.1. Establishing Effective Measures

Key Performance Indicators

The interaction between leading and lagging indicators is illustrated by Liu et al. (2019):

1. Leading Indicators

   Leading indicators are utilized for project objective monitoring and future event anticipation. Depending on the project's unique needs, these indicators may be adjusted to align with the organization's traits, goals, resources, and rules. they identify critical leading indicators in systems engineering, like requirements trends and technology maturity.

2. Lagging Indicators:

   These indicators offer a retrospective view of project performance, focusing on outcomes like personal safety metrics. These indicators are useful for measuring direct outcomes while it's limited in providing proactive insights.

Liu et al. (2019) conclude that while leading indicators are valuable for a predictive approach to project management, a balanced integration with indicators is essential for a comprehensive performance measurement framework.

Effective Metrics

The effectiveness of safety performance indicators in process industries relies on the SMART criteria—Specificity, Measurable (or Manageability), Achievability, Relevance, and Time-based. Analysis shows that to be effective in barrier management, an indicator must meet all these criteria. Selvik et al. (2021) discuss the possible redundancy of the 'M' criterion—Measurability arguing that meeting the other criteria might offset any concerns about measurability or manageability, emphasizing the importance of the other four criteria in assessing safety performance indicators.

2.1.7.2. What to Measure

Table 1 summarizes various metrics for evaluating project performance, including error analysis, workflow efficiency, baseline cost and schedule adherence, resource productivity, and stakeholder satisfaction.

Table 1: Key Metrics for Evaluating Project Performance

Metrics	Description	Source
Deliverable Metrics	**Information on Errors or Defects**: Methods to assess defect impacts, considering frequency, financial implications, customer satisfaction, and prevention costs.	Milion et al., 2021
	Measures of Performance: Building comfort metrics including energy efficiency, and indoor quality, using synthetic metrics for comfort conditions.	Atzeri et al., 2016
	Technical Performance Measures: Material strength, safety adherence, and environmental compliance.	Tahira, 2007; Orogun & Issa, 2021; Lützkendorf, 2017
Delivery	Workflow metrics identify delays from non-value-adding activities, using Little's Law for efficiency.(TH = WIP/CT)	Sacks et al., 2017
Baseline Performance	Analyzes cost and schedule baselines, focusing on project cost, duration changes, and overages.	Ramsey and Asmar, 2020
Resources	Uses metrics like the Maturity Index (MI), Task Completion Risk (TCR), Task Readiness (TR), and Location Risk Index (LRI) to assess resource utilization against productivity.	Pal et al., 2023

2.1.7.3. Innovative Metrics, Analytical Tools, and Communication Strategies

Review and Adjust

Domínguez et al. (2019) examined the process of aligning Key Performance Indicators (KPIs) with the changing requirements of the organization. To achieve this, the researchers reevaluated the objectives that the KPIs track, adjusted the targets to correspond with the new organizational goals, and updated the measurement methods to reflect the present operations.

2.1.8. The Uncertainty Performance Domain

Uncertainty is the unpredictability of performance, primarily due to the inherent complexity and existing uncertainties within project networks. These uncertainties can cause disruptions, altering the network's original topology and affecting project performance (Zhu and Mostafavi 2015).

2.1.8.1. Ambiguity

Solutions for exploration of ambiguity

1. *Progressive elaboration*

   According to Abualdenien and Borrmann (2022), the process of progressive elaboration improves work management and estimate accuracy through the iterative refinement of plans. They illustrate how structures commence as rudimentary models and progress utilizing updates that integrate intricate details, including material properties and structural calculations. By implementing this procedure, the accuracy, quality, and uniformity of the model are improved, and all stakeholders agree for the duration of the project.

2. *Prototypes*

   Johnston et al. (2016) emphasize the advantages of virtual prototyping in the construction industry by simulating the assembly of a mobile test laboratory using sophisticated software. The research utilizes virtual prototypes as a means of conveying constructability information non-verbally. It illustrates the effective integration of architecture, engineering, and construction information through virtual prototyping, which effectively resolves ambiguities that may arise in complex projects.

2.1.8.2. Complexity

Complexity arises due to multidimensional and dynamic interplay between different stakeholders. They perceive complexity based on criteria relevant to their roles. For example, contractors might emphasize operational and technological complexities, while investors may focus on financial and strategic aspects (Nikolić & Cerić, 2022).

Approaches to Handling Complexity

1. Systems-Based
   a. Work breakdown structure (WBS)

Using a database design based on Work Breakdown Structure (WBS), Park and Cai (2017) tackle the challenge of assimilating varied and unstructured construction records into digital modeling systems. this database incorporates construction records, enhancing data structure with an automated linking mechanism that connects project tasks to digital model objects. The method's practicality and effectiveness were validated in a construction project, producing detailed as-built documentation. As shown in Figure 3, WBS-based design used to create a comprehensive BIM database, demonstrating the integration and management of construction data through advanced BIM technology and structured WBS methodology.

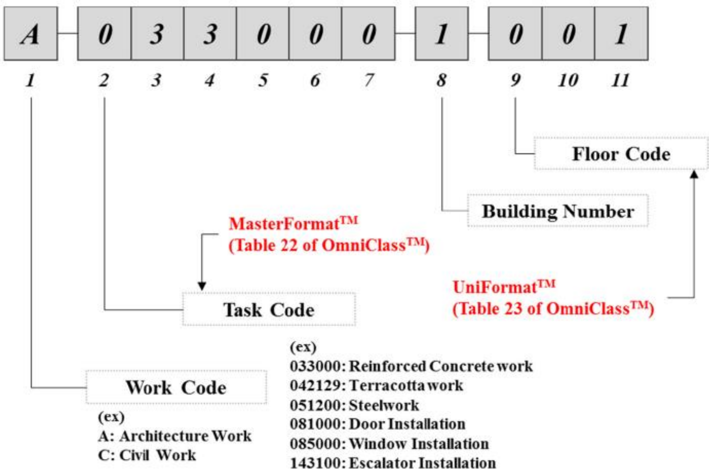


Figure 3: WBS code structure in Park and Cai (2017)

b. Simulation

Abdullahi et al. (2023) indicate that the utilization of digital methods, including augmented reality (AR), virtual reality (VR), and 3D models, might enable project managers to coordinate and allocate resources in realtime, thus effectively managing the inherent complexities of large-scale construction environments.

2. Reframing

a. Interdisciplinary Collaboration

Idi and Khaidzir (2018) indicate that the bulk of studies on design collaboration have primarily concentrated on interdisciplinary design collaboration and teamwork through digital modalities. the study also highlights several themes central to design collaboration: teamwork, Building Information Modeling (BIM) framework, Evidence-Based Design (EBD) practice, and Modality-Supported Collaboration Design (MSCD).

3. Process-Based
    a. Iteration process

    Understanding customer requirements is the foundation for functional analysis, which is vital in complex project management, according to Redmond and Alshawi (2017). The process advances via a verification loop that is specifically designed to assess adherence to the initial system specifications. It ultimately concludes with the synthesis of the system architecture, which guarantees compliance with the stated specifications. With the assistance of a consulting team that assesses cost-effectiveness and project management, the design loop integrates these phases, thereby facilitating the development of system architecture from fundamental to specific requirements. By employing an iterative process that involves ongoing refinement and adaptation in response to new information, one can effectively manage complexities and efficiently resolve issues.

2.1.8.3. Risk

Key challenges identified by Abdel-Monem et al. (2022) include unattainable deadlines and decreased productivity. The authors further classify risks into three categories: technical, financial, and environmental. For the most accurate assessment of opportunities and threats, emphasis is placed on the utilization of risk registers and similar tools. Similarly, Z. Jin et al. (2019) stress the importance of a predefined risk threshold reflecting the acceptable level of risk agreed upon by stakeholders. Established before risk assessment based on criteria such as time or area, this threshold aligns with stakeholders' risk appetite and guides the thorough examination of project elements—such as duration, designers' qualifications, contractors' safety records, and owners' contingency plans—to ensure a strategic approach to risk management.

Threats

Project progress, profitability, sustainability, and integrity may be compromised by threats, encompassing both internal and external elements. By delineating strategic responses—including avoidance, escalation, transfer, and mitigation— as explained in Table 2 to efficiently oversee said risks, scholarly conversations in risk management attend to these concerns.

Table 2: Risk Management Strategies

Strategy	Description	Key Insights	Source
Avoid	Eliminate project risks early.	Efficiency and cost-effectiveness	Othman and Alamoudy (2021)
Escalate	Invoke external intervention for uncontrollable risks.		X. Liu et al. (2019)
Transfer and Mitigate	Splitting risk for transfer or mitigation in complex projects; uses insurance, contracts, and direct actions.	Optimize resilience and continuity by leveraging external resources for unavoidable risks and reinforcing internal practices against preventable threats.	Gregory M (n.d.)
Accept	Tolerate manageable risks with preparedness.	Enhance safety and operational efficiency by strategically accepting manageable risks, and focusing resources on mitigating higher-impact threats.	David (2001)

The primary objective behind the application of these threat response strategies is the minimization of adverse risks. It is noteworthy that some risks, when accepted, may diminish over time or may not materialize as anticipated risk events, thereby naturally reducing their impact without the need for active mitigation measures.

Opportunities

Johansen et al. (2016) emphasize the potential positive outcomes of opportunities is frequently disregarded. Such opportunities frequently necessitate reevaluation of previous solutions and modifications to contracts, highlighting the need for a balanced approach to opportunity and risk management. Table 3 presents various opportunities management strategies and their key insights

Table 3: Opportunites Management Strategies

Strategy	Description	Key Insights	Source
Exploit	Enhancing benefits by utilizing opportunities.	Stakeholder involvement shifts towards value maximization.	Eskerod et al. (2018)
Escalate	Used when an opportunity exceeds project scope or authority.		
Share and Enhance	Transferring opportunity to better-suited parties.	Effective for high-impact opportunities, fosters partnerships.	Sanghera (2018)
Accept	Accepting an opportunity without extra effort.	Maintains balance when benefits don't justify extra resources.	David (2001)

Risk Review

1. Establishing Review and Feedback Sessions for Stakeholders
   Liu et al. (2023) assert that the implementation of consistent monitoring and emergency planning, coupled with the utilization of dynamic feedback, serves to iteratively enhance risk management strategies. This iterative process not only

enhances project effectiveness but also establishes a solid foundation for the prevention of risks. According to Zou et al. (2017), the incorporation of daily standup meetings enables the prompt recognition of risks and opportunities, thereby fostering swift project adaptation and making a substantial contribution to proactive risk management strategies

2. Visual Demonstrations

   Visual demonstrations of product increments and designs function as an early warning system in project management, effectively identifying potential risks and opportunities through the analysis of project data, encompassing costs and schedules. According to Sun et al. (2015), these demonstrations serve the purpose of identifying risks, such as stakeholder dissatisfaction resulting from negative feedback or indicating high-value areas through positive feedback. As a result, they guide decision-making and strategy adaptation.

3. Retrospectives and Lessons Learnt Meetings

   Upon project completion, it is essential to identify potential risks to performance and team unity, while also exploring opportunities for improvement. This tackles obstacles such as the loss of detail due to delays in documentation and a culture of blame that obstructs truthful reporting. However, it is crucial to emphasize the importance of identifying strategies to capitalize on opportunities and advance project management methodologies (Marle, 2020).

2.2. History of BIM

BIM originated conceptually and was developed at the Georgia Institute of Technology in the late 1970s. Since then, it has evolved significantly ("Building Information Modeling," 2019). The expansion occurred as a result of the necessity to establish construction teams and firms that recognized the benefits of BIM in effectively facilitating, integrating, and managing construction projects (Nushi & Jakupi, 2017). ArchiCAD, by Graphisoft, was the first "virtual building solution" in 1986. With this innovative new program, engineers can generate virtual three-dimensional (3D) models of their projects instead of 2D (two-dimensional objects found in CAD software). This allowed the engineers to store large datasets within the building model. These data sets include building geometry and spatial data, as well as component properties and quantities (Salehi, 2012). Then, in this decade, various BIM authoring programs were developed, and they are growing strongly. When Autodesk released "Building Information Modeling," the term "BIM" were extensively used.

2.3. Building Information Modeling Aspects

2.3.1. Information Management in the BIM Process

This section is dedicated to an in-depth exploration of the complex processes of data collection, storage, sharing, and utilization that are integral to BIM, emphasizing their importance in construction project management.

2.3.1.1. Establishment of Development of Information Requirements

The potential benefits of incorporating ISO 19650's core principles into Enterprise BIM, which cover a wide range of information requirements and shared data environments.

According to Godager et al. (2022), the fundamental Level Of Information Need (LOIN) determines the amount of information needed at each stage of an asset's life cycle (Figure 4). Applicable to a variety of information requirements, including different levels and shared data environments.

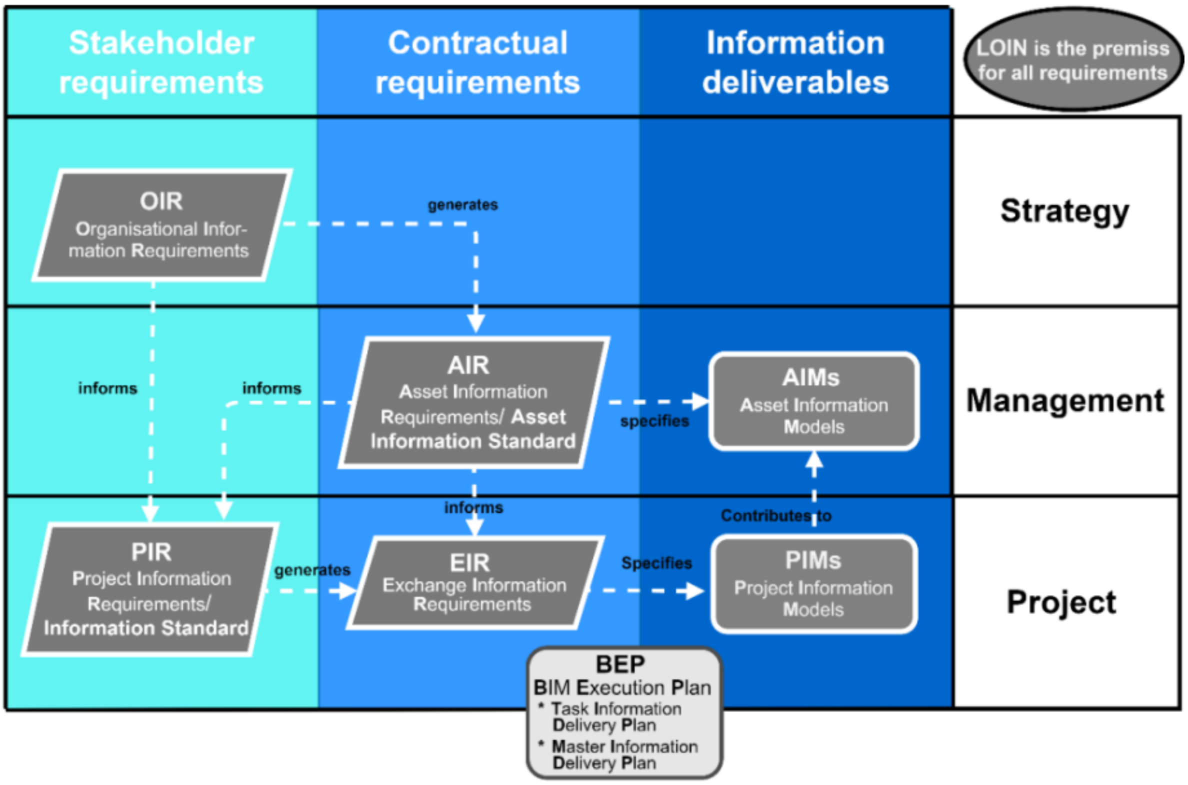


Figure 4: Information management throughout the value chain, based on (ISO 19650, 2018)

Table 4: Overview of BIM Information Requirements

Information Requirements	Purpose	When Define	Who Creates Them	Contents Include	Examples
OIR	High-level needs for organizational functions.	During strategic planning.	Senior management or planners.	Goals, efficiency, compliance, support.	Health and safety protocols, environmental frameworks.
AIR	Manages specific assets, focusing on maintenance.	At asset planning and throughout lifecycle.	Asset managers or teams.	Performance data, maintenance, lifecycle info.	Maintenance schedules, metrics, insurance details.
PIR	Needed for project design and construction phases.	At project initiation and throughout lifecycle.	Project managers with clients and architects.	Project goals, design info, compliance requirements.	Design data, construction timelines, approvals.
EIR	Details for information exchange between project parties.	Before project start and at each phase.	Project managers, with stakeholders.	Exchange formats, delivery timelines, security.	Exchange protocols, specific requirements, phase transitions.

Table 4 categorizes Information Requirements (IR) in construction project management by purpose, timing, creators, contents, and examples. It details Organizational (OIR), Asset (AIR), Project (PIR), and Exchange Information Requirements (EIR), highlighting their roles in strategic planning, asset management, project execution, and information exchange.

2.3.1.2. Information Delivery Planning

The Master Information Delivery Plan (MIDP) and Task Information Delivery Plans (TIDPs) delineate the specific information that is to be disseminated, the format in which it is to be delivered, and the project stages at which it is to be delivered.

The MIDP serves as the main strategy for overseeing the dissemination of information throughout the entire duration of the project, whereas the TIDPs are consolidated compilations of information deliverables for each task, encompassing their structure and deadline. The methodology described follows the guidelines set forth by the British Standards Institution, thereby guaranteeing adherence to ISO 19650 and the UK BIM Framework (Shojaei et al., 2022).

2.3.1.3. Quality Control and Validation

Chen and Luo (2014) developed a tool for quality control and validation using 4D Building Information Modeling (BIM). This study aimed to evaluate the compatibility between Building Information Modeling (BIM) technology and existing quality management procedures, identify any potential challenges, and propose potential solutions.

The characteristics of this system encompass efficient management and monitoring of construction processes and materials, adherence to established standards and regulations, integration of quality and scheduling frameworks to enhance planning and supervision, and virtualized capabilities for simulating and visualizing construction scenarios.

2.3.1.4. BIM Execution Plan

The BEP (BIM Execution Plan) assists the owner in selecting a delivery team capable of meeting EIRs. The contents of the document play a crucial role in the team's decision-making process, and its creation should include a collective endeavor, while also answering inquiries outlined in the bid invitation (Sáenz et al., 2018).

The BEP may include roles and responsibilities, information delivery and model federation strategies, a high-level responsibility matrix, amendments to information standards, and a Technology Enablement Schedule, in one or multiple documents.

2.3.2. Technical Aspects of BIM

This chapter describes specific BIM functions, which are connected to common features that are provided within the BIM levels (Sacks et al., 2018)

1- Collisions detection: To detect collisions, multiple disciplines' building information models are combined and checked for geometrical design errors. When models from many disciplines are combined, points, where they overlap, are found and adjusted. Additionally, visual defects that result in lower aesthetic quality can be detected and repaired. Figure 5 depicts a collision between a beam and a ventilation duct identified through BIM collision detection, necessitating design adjustments to rectify the overlap.

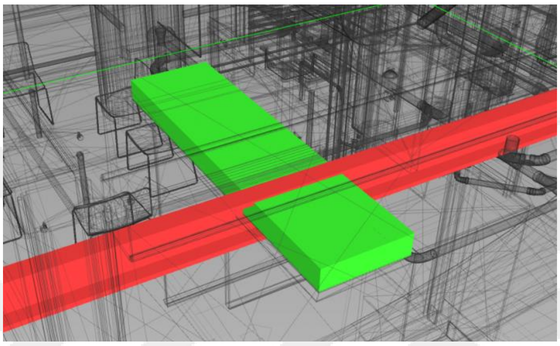


Figure 5: Clash detection by Naviswork

2- Analyses of energy: An energy analysis may be accomplished by integrating a building information model with instruments that assess optimum energy demand for heating and cooling. Energy analyses help to create buildings that use less energy during their lifetimes.

3- 4D Scheduling: The items in a building information model are connected to the time plan using time estimation, often known as 4D. The connection to the time plan allows users to visually see the project's timeline and simulate the building site and construction at any point in time. This simulation technique gives a great deal of knowledge and enables the early discovery of planning problems. It is possible to avoid costly mistakes in the design phase rather than later in the construction process.

4- Cost estimation (5D): Using a cost estimate, often known as a 5D, the items in a 3D design may be linked with price lists for various materials. The price lists are mostly based on material volume prices, but they may also include labor and equipment expenses for more thorough cost estimates. This allows for accurate cost prediction at any stage of the design process and improves knowledge of the financial consequences of design choices. As a result, materials and building options may be assessed economically.

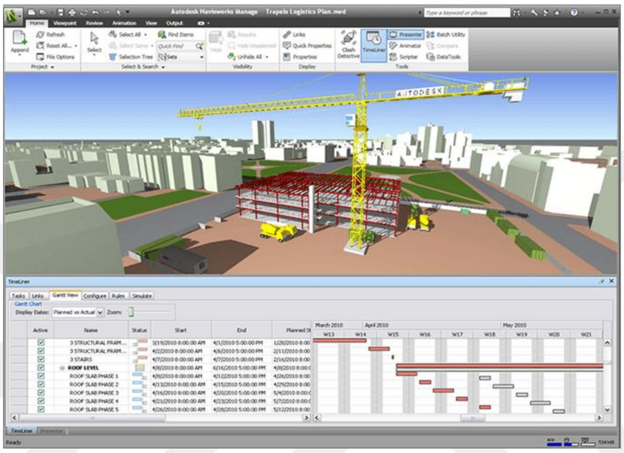


Figure 6: 4D & 5D Scheduling

Figure 6 exemplifies 4D and 5D scheduling in a building information model, showcasing how the integration of time planning and cost estimation (respectively) enables visualization of the project timeline and financial analysis at any design stage,

5- Quantity Take-off: To examine choices and have a clear and reliable view of various alternatives, quantity takeoffs in a BIM model may be highly beneficial for project teams and management. Because the BIM model and a database providing cost estimates may be integrated, an accurate estimate can be achieved faster. These takeoff items may also be applied in procurement.

2.3.3. BIM Collaborative Framework

2.3.3.1. Appointment of Key Roles

Davies (2017) conducted an extensive analysis of 36 international BIM standards and guidelines, highlighting the requirement for consistency in the delineation of these obligations. The author posits that a significant degree of perplexity results from the lack of universally recognized definitions and the presence of individualized employment prerequisites for each client. As a result, this underscores the critical necessity for the Building Information Modelling (BIM) sector to establish unambiguous job descriptions and expectations to facilitate enhanced communication and streamlined project execution.

Table 5: Expectations of selected BIM roles (Davies, 2017)

Role	Technical	Process	People	Strategy
BIM Manager (project role)	Oversee software functionality, model content suitability, and deliverables creation.	Spearheaded the BIM Management/Execution Plan; managed file coordination and revisions.	Primary liaison for BIM issues; educate and manage project team's BIM responsibilities.	Ensure adherence to project BIM strategies and guidelines.
BIM coordinator (project role)	Execute clash detection and model integration checks.	Maintain and update the BIM Management Plan as necessary.	Facilitate cross-disciplinary communication and BIM troubleshooting	Manage quality control and report generation within the discipline.
BIM modeler (organizational role)	Generate and update discipline-specific models.	-	-	-
BIM Manager (organizational role)	Set up and apply BIM technologies and standards.	Establish and improve organizational BIM processes.	Lead BIM training and change management.	Develop organizational strategies for BIM adoption and integration.

Table 5 presents an all-encompassing overview of the diverse and complex responsibilities inherent in Building Information Modeling (BIM) projects. It highlights the technical, procedural, human, and strategic dimensions that are linked to each role (Davies, 2017).

2.3.3.2. Use of Common Data Environments (CDE)

The implementation of a Common Data Environment (CDE) ensures the maintenance of uniformity and reliability through its role as a digital platform that gathers, oversees, and distributes project-related data.

According to Losev (2020), CDEs possess a range of functions that extend beyond their traditional role as electronic document management tools in the routine operations and design procedures of buildings and structures. This proposal suggests a significant shift in viewpoint, where CDEs are analyzed within the framework of managing the entire lifespan of buildings, transitioning from a data-focused approach to a knowledge-focused methodology. This perspective aims to establish a comprehensive ontology for the concept of the life cycle of structures and buildings, bolstered by a model centered around data exchange(Figure 7).

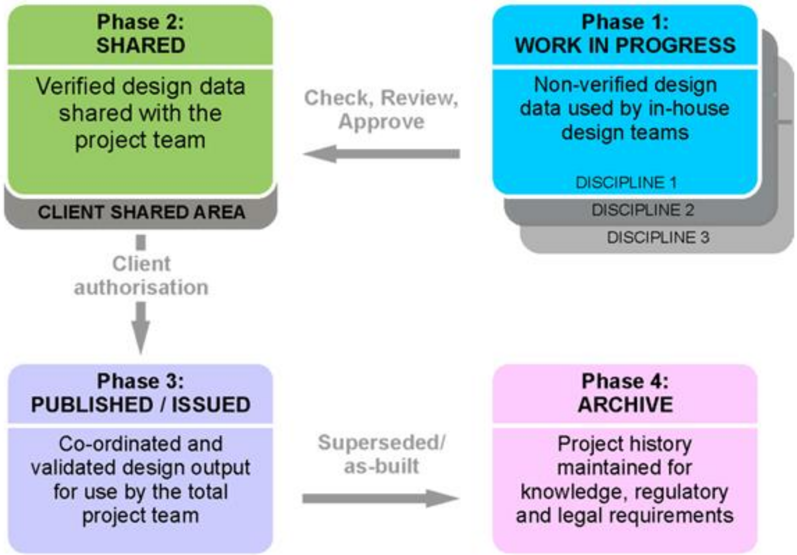


Figure 7:CDE concept as demonstrated in ISO 19650-1

2.3.3.3. Integrated Project Delivery System IPD

IPD is primarily promoted as a delivery method for its integration with Building Information Modelling/Management (BIM) on construction projects. BIM promotes "Integrated Project Delivery," an innovative approach to project delivery that integrates people, systems, work structures, and practices into a unified process to maximize efficiency, effectiveness, productivity, performance, and waste reduction throughout the project life cycle. IPD aligns the project team's incentives and goals through shared risk and reward and the early involvement of all stakeholders. Additionally, BIM is not simply a software program; it is a process that entails significant changes in workflow, project management, and delivery. Along with clearly defined work scope, roles, relationships, and responsibilities, clearly defined contractual relationships, early project goal definition, and early team formation are indicated to be the most critical factors in IPD success. As a result, IPD is consistent with the characteristics of successful integration processes (Dalui et al., 2021).

2.3.3.4. Collaboration and Communication

The authors, Das et al. (2015), emphasize the implementation of regular coordination meetings and the utilization of the BIMCloud architecture. By utilizing a cloud-based BIM server infrastructure, this system optimizes the exchange of BIM information through the dynamic consolidation and partitioning of building models. The data model utilized in this research is founded upon Industry Foundation Classes (IFC) and has been significantly improved to incorporate social interactions, which are consistent with the conventional communication approaches frequently employed in the AEC (Architecture, Engineering, and Construction) industry. These interactions are managed by a BIM-based graphical user interface on an object-based system.

2.3.3.5. Training and Competence

The research conducted by Shojaei et al. (2022) examines the strategies used by UK construction companies to tackle training and competency obstacles in Building Information Modelling (BIM), with a specific emphasis on ensuring compliance with ISO 19650. The evaluation examines existing training methods and highlights the need for customized programs that address both technical BIM competencies and ISO 19650 requirements.

2.4. Related studies on BIM Implementation and PMBOK principles:

Table 6 summarizes prior research and methods using BIM in project management knowledge in the construction sector.

Table 6. Prior research methods in project management and construction sector

SN	Reference	Method	Applied Sector
1	Zahiroddiny, 2016	• Pilot study • Focus group • Disruptive analysis	Construction industry
2	Rezahoseinia et al., 2018	SAW analysis	Project knowledge areas
3	Maliha et al., 2020	• Pilot study • Descriptive statistics	Project knowledge areas
4	Gerges et al., 2017	• Pilot study • Descriptive statistics	Existing implementation techniques of BIM in the Middle East construction project

SN	Reference	Method	Applied Sector
5	Olanrewaju et al., 2021	Structural equation model	Construction industry
6	Aladag et al., 2016	• Pilot study • SMART	Turkish construction industry
7	Prabhakaran et al., 2021	• Descriptive statistical analysis • Inferential statistical analysis	Qatar and the United Kingdom's construction industry
8	Kaya et al., 2020	• Descriptive statistics • 5-point Likert scale	Level of risks in construction projects.
9	Didehvar et al. (2018)	• one-sample T-test • Kolmogorov-Smirnov approach	Virtual Information Modeling on Project Management Knowledge Areas
10	Chen et al. (2023)	• Comprehensive Literature Analysis • Analysis of Open Specification Formats • Utilization of Autodesk Revit	potential features of (BIM) for the application of project management knowledge areas

Zahiroddiny (2016) investigated the challenges surrounding the usage of e-mail and BIM and addressed the possibility of BIM to boost electronic communication as a result of conventional and fragmented working patterns. The purpose of the research was to comprehend the effects of Building Information Modelling (BIM) on the communication patterns of building projects and to find the foundation for individuals to better comprehend why communication is crucial and required for collaborative working. A Pilot Study was used to investigate the existing communication practices and to determine which communication protocols are more important to project groups. Focus Groups were utilized to confirm the preliminary research data and descriptive analysis was applied to predict the effects BIM may have on the electronic communication practices of construction projects. The study's findings suggest that conventional work environments are complex and lack a unified platform for communication and a cohesive approach to information exchange. In addition, it was retorted that BIM brings new methods of working through a new set of technologies that use object-based and data-rich information models for sophisticated information management. Technology, Process, and People have been recognized as crucial areas to address to prevent a rise in communication utilizing discipline-based information models. To conclude: Consequently, e-mail has not been an entirely successful communication channel, even without the use of BIM, and the deployment of Autonomous

BIM will cause e-mail users to be more overburdened than before since BIM facilitates the creation and extraction of electronic drawings/documents.

Rezahoseinia et al. (2018) investigated the project's knowledge management areas and how they interconnect, before explaining building information modeling (BIM) and its capabilities throughout the project's life cycle. The research concludes that each of the fundamental BIM skills has a favorable impact on various areas of PMBOK knowledge. Furthermore, simple additive weighting (SAW) analysis was being used. The study discovered the impacts of BIM capabilities on PMBOK knowledge areas using expert interviews and questionnaires, and it examined the experts' views on these two topics' mutual effects on each other. The research revealed that BIM capabilities are influential in all areas of knowledge, with the largest influence on integration management and the suggested BIM process model for implementing knowledge management in the project's knowledge management areas.

Maliha et al. (2020) conducted a study to comprehend the contribution of BIM technology to the advancement of Knowledge Area application in the AEC business. The study's technique for analyzing the influence of BIM technology on the body of knowledge is extensive. It was decided to conduct a pilot study based on the first draft, which was then modified and improved upon. Proposed quantitative data analysis procedures include Pearson correlation analysis and reliability test. The descriptive statistics mean SD, t-value (two-tailed), P-value, RII, and rankings were determined. As a consequence, the research suggests that the most significant positive association was discovered between BIM technology in the AEC business in Palestine and the knowledge areas of “Time Management, Cost Management, Integration Management, and Communication Management”. In addition, the research suggests increasing BIM knowledge among project managers, particularly in the construction sector, to support the use of knowledge areas (KAs)in all projects and to utilize BIM as a management tool rather than a technical tool.

Another research by Gerges et al. (2017) investigated the existing implementation techniques of BIM in the Middle East. An online survey with twenty-six questions was created to gather data on the various features of the respondents. In the Middle East, the application and usage of BIM have risen. As a consequence, sixteen BIM tasks and functions have been identified. "Analyze models for coordination or conflict detection," "engage others in BIM use (colleagues, subordinates, subcontractors, owners, etc.)," and "extract estimates from BIM models" are the highest-rated aspects. According to this research, the United Arab Emirates is the Middle Eastern country with the largest number of BIM projects. Lebanon and Jordan, on the other hand, have the fewest BIM projects. Furthermore, the greatest perceived barriers to BIM application were "BIM to CAD comparisons." This was followed by "resistance to change" and "contractors see BIM as an added cost."

Using Structural Equation Modeling (SEM) to find links between structures, Olanrewaju et al. Study (2021) performed a novel investigation of the influence of BIM drivers on use and awareness across the project lifecycle. In this research, "construction, digitalization of operations and economics, sustainability and efficiency, visualization and productivity" were identified as crucial BIM drivers. In addition, knowledge of BIM models throughout the operational phase of the project lifecycle has a substantial effect on BIM adoption drivers. In addition, the survey revealed a lack of understanding of facilities management, an essential part of the operational phase. This research offers construction businesses essential drivers that may be utilized for global market competitiveness and survival by integrating BIM and supports customers, contractors, and consultants in analyzing BIM drivers.

Aladag et al. (2016) researched to analyze the Turkish construction sector to establish a comprehensive grasp of BIM and to examine its obstacles and advantages. Six participants from construction businesses and colleges participated in focus group talks. SMART, a multi-attribute decision-making technique, was used to examine the gathered data. As a consequence, "acquisition of enterprises" has the greatest influence on the Turkish construction industry's adoption of BIM, but "organizational structure and culture" is the most significant barrier to BIM adoption in the Turkish sector. In addition, "customer demand/contract duties" and "need for cooperation, coordination, communication, and interoperability across stakeholders" are seen as the most crucial elements relating to industrial BIM adoption needs. Also, it is assumed that "customer happiness" rather than "raising the firm's overall profitability" is the most essential acquisition consideration.

Prabhakaran et al. (2021) researched the maturity of large-scale BIM in Qatar and the UK using existing maturity models to corroborate the UK's BIM maturity. The specialists were charged with visualizing BIM maturity and organizational factors impacting it in Qatar and the UK. Qualitative objective research of open answers was done to understand the reasoning behind experts' BIM maturity rankings. Descriptive statistics were used to describe the sample and its measures, while inferential statistics helped discover patterns in the data. This study solves the problem by implementing 23 macro-level BIM settings. Micro-level firms believe champions and drivers are important for implementing BIM models. Champions, drivers, and important publications influence an organization's maturity in the UK. This study suggests reviewing BIM implementation standards with individuals, groups, and organizations.

Kaya et al. (2020) examined the use of BIM for risk management in building projects. A questionnaire was designed to elicit responses from 65 building project management and BIM specialists. The results of this study indicate that BIM may bring substantial advantages to risk management throughout the life cycle of a project due to the identification and mitigation of hazards as early as feasible, particularly during the design and planning stages. According to the results of the research, participants feel that BIM's conflict detection procedure may reduce construction and implementation risks. Moreover, BIM can be utilized to visualize risk information for various stages of a project. Throughout this study, the link between BIM and risk management is also examined in terms of quality management.

In their investigation on the acceptance of Virtual Information Modeling (VIM) based on project management knowledge areas, Didehvar et al. (2018) conducted a thorough study to understand the benefits and challenges of VIM in the construction industry. Employing a one-sample T-test combined with a Kolmogorov-Smirnov approach, the research analyzed responses from a structured questionnaire survey. This survey targeted project managers working in architecture, engineering, and construction industries in Tehran, Iran, and achieved a 64% response rate. The results of this study highlighted that the most significant benefits and challenges of utilizing Virtual Information Modeling are intricately linked to the area of integration. The study further revealed that the implementation of VIM has a considerable impact on project integration management knowledge areas, significantly more than other project management knowledge areas. This suggests that VIM is not just a technological tool but a critical component in the integration and management of construction projects.

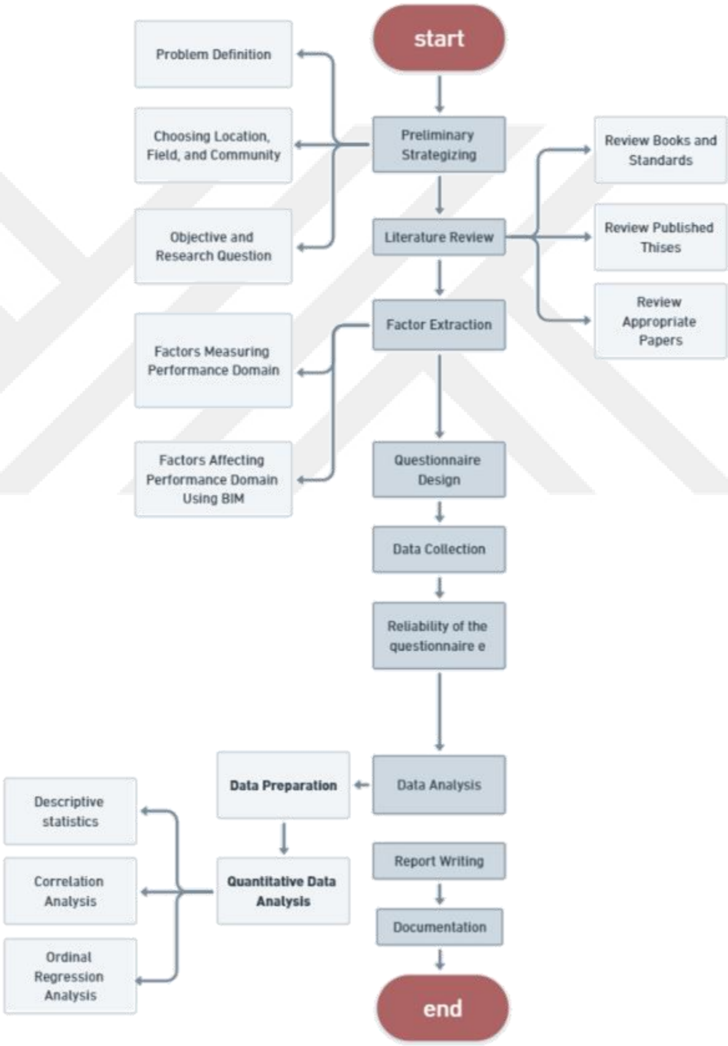
In the study by Chen et al. (2023), the potential features of Building Information Modeling (BIM) are explored for application in project management knowledge areas as advanced modeling tools. The research focuses on the Architecture, Engineering, and Construction (AEC) industry, highlighting its significant role in infrastructure development and its impact on the socioeconomic status of countries. The study acknowledges the challenges in project management, particularly in the context of BIM design, which includes issues such as preparation of a building execution technology project, adherence to existing standards, and effective information collection during the building's exploitation period. The primary objective of the research is to analyze the application of project management knowledge areas (PMKA) in the construction industry and to assess the advantages and limitations of using BIM technology as a tool to enhance the utilization of PMKAs. The study investigates how BIM can be employed for project management and how it can be used to gather knowledge for creating a BIM model. The study demonstrated that Building Information Modeling (BIM) enhances construction project management through improved information sharing using IFC and XML formats, effective application in healthcare-related projects, support by Autodesk software like Revit and AutoCAD, advancements in construction activities including planning and 3D coordination, and 4D scheduling while highlighting the need for further research in technology adoption and stakeholder training to optimize industry performance.

2.5. Research Gaps

The literature on the added value of BIM aspects is extensive, however there is a lack of research on how these aspects impact the different project performance domains addressed in the PMBOK standards. In addition, the literature lacks studies on how to structure BIM training programs to address the specific, comprehensive needs of the region. The literature also lacks studies on how to better integrate BIM aspects into contemporary project management. This study provides the first limited exploration of how to integrate these aspects into the PMBOK standards. This study helps to fill the knowledge gaps related to BIM implementation and its relationship to project management.

3. METHODOLOGY

The objective of this chapter is to establish the research philosophy and investigate the methods and assumptions that underpin the research. The methods of data collection and sample size determination were also thoroughly described. This chapter also specified and explained the tests that were selected to address the research questions, as well as the type of reliability, in order to ensure that the results were consistent and pertinent.



This framework explains how the study methods were used to answer the main questions of the study, guided by the insights derived from the literature review and identifying the key variables that comprise the different BIM aspects and performance domains in the project. Once the data collection is complete through the questionnaire, the collected data must be ensured to be reliable through reliability analysis. To achieve the research objectives, the collected data was processed and analyzed, where descriptive statistics were applied, which provides an overview of the collected data and an understanding of the distributions by the project characteristics of the respondents. In addition, correlation analysis for BIM aspects to understand which BIM variables work together effectively and to know the relationship between them. The primary analysis in the study consists of ordinal regression to investigate deeper relationships between variables that highlight the relationship between the impact of BIM aspects on different performance domains. This analysis shows the degree and influence of each BIM feature on different domains, revealing how well BIM improves them.

3.1. Design of Research

A quantitative deductive approach was developed to evaluate the extent of the impact of BIM aspects on performance domains within AEC in the MENA. This approach includes descriptive research and correlational research, with a particular emphasis on regression analysis.

This method entailed the collection and statistical analysis of data to test the hypotheses that the eight aspects of BIM contribute to enhancing performance domains in the project and answering the primary research questions. The hypotheses were tested using inferential statistical methods to determine whether the data collected was sufficient to refute the null hypotheses. The methods of collecting cross-sectional data were used to derive conclusions about the opinions of the participants.

The methodology implements a variety of statistical analysis techniques; however, the Ordinal Logistic Regression is of paramount importance in comprehending the influence of BIM components on project performance domains. This approach is employed to quantify and model the impact of various BIM components on critical performance outcomes, thereby substantiating the study's hypotheses with empirical evidence.

3.2. Research Philosophy

The study was founded on the positivist cognitive philosophy, which is predicated on the positive confirmation of theories and is based on pure scientific knowledge. This philosophy underscores the importance of empirical evidence and objective methodologies in the collection and analysis of data.

3.3. Methodology for Data collection

The SurveyMonkey survey platform was employed to disseminate the questionnaire to the participants, and a questionnaire was developed with closed-ended questions. In order to expedite the collection of information and facilitate the comparison of current standards and practices in the fields of architecture, engineering, and construction in the MENA, cross-sectional data was implemented.

The questionnaire was developed in accordance with the objectives and research questions delineated in paragraph (1.2). The questionnaire was structured according to the Likert scale, which ranges from vehemently disagree to strongly agree. Typically, this measure is employed to express an opinion regarding a particular statement or paragraph, in which respondents select the option that most closely aligns with their opinions regarding the statement. Burchell and Marsh (1992) have confirmed that the length of a survey questionnaire can be a factor that negatively reflects the desire to complete it for a large number of people. Consequently, the questionnaire's length was examined, and it was determined that it can be completed within 5 minutes to increase the response rate and obtain an effective sample in record time.

3.3.1. Sections of The Questionnaire

The questionnaire was divided into four sections, as illustrated below:

Section 1: Experience with BIM

This section ascertains whether the BIM system has been implemented in the institution and the projects of the participants, and if so, the extent of its implementation. This presentation enables us to ascertain the current stage of BIM application and to quantify the degree to which one level differs from others and the extent to which it influences the opinions of the participants.

Section 2: **Respondent and Project Background Information**

In this section, fundamental data was gathered, including the project's nature and the team's level of expertise. The results of this data will indicate the degree to which at least one group deviates from the other groups and the extent to which it influences the participants' perceptions of the impact of BIM aspects on the performance domains of the project.

Section 3: Performance Domains Assessment

This section assessed eight performance domains, with the objective of assessing the quality and management of these domains, as well as their efficacy within the undertaking in which the respondents are involved. This section offers insight into the current state of performance management implementation in the Middle East and North Africa. More importantly, these responses are the response variables that were employed in the logistic regression analysis to assess the extent of the influence of BIM aspects on them.

Section 4: Specific BIM Aspects and Their Implementation

The objective of this section is to gather feedback from the participants regarding the management of BIM aspects and their influence on project performance. It also serves as a means of assessing the detailed visions regarding the application and success of BIM aspects in the actual projects specified in paragraph (1.6.1). These responses serve as predictor variables for the logistic regression analysis of the project's performance domains .

Purposive sampling was implemented due to the research's emphasis on experienced participants and its utilization of a particular system. It is a non-probability method in which the researcher selects participants based on specific characteristics and experience. Subsequently, the questionnaire is distributed to their acquaintances who share similar characteristics. This method enhances the quality and validity of the data, resulting in the acquisition of dependable results.

The sample representation guarantees that the majority of sectors associated with construction are represented, including consultants, engineers, and employees of both public and private institutions.

3.4. Reliability Analysis.

The statistical approach employed to collect data is designed to guarantee the reliability of the survey instrument across the selected sample.

To assess the extent to which the items in the questionnaire are consistent within the same construct, the sample's internal consistency ratio was achieved. To accomplish this, Sürücü and Maslakçi (2020) elucidated that Cronbach's alpha coefficient is employed as an appropriate instrument for evaluating the questionnaire's internal consistency.

The internal consistency reliability was assessed and determined for each performance domain and the survey evaluated all aspects of BIM. Cronbach's alpha values exceeded 0.75 for all constructs, suggesting satisfactory reliability. This analysis guarantees the quality of the analysis, the quality of the data collected from the participants, and the confidence in the research results.

3.5. Analytical Framework

3.5.1. Descriptive statistics

The data was summarized to offer a preliminary understanding and quantitative descriptions in a format that is easily manageable. The focus was on the central tendency, dispersion, and shape of the response distribution, including the demographic and occupational characteristics of the participants, as well as the identification of patterns and trends in the responses related to BIM and performance domains .

Due to viloaite the normality in data set non-paramatric testes like Kruskal-Wallis H and Chi-square were employed to compare the mean scores across regions and BIM levels in order to evaluate the distinctions between performance domains and geographic locations. Chi-Square Tests are used to assess the distribution of BIM levels across different locations and organizational categories. Furthermore, Kruskal-Wallis H is employed to ascertain whether project complexity ratings vary by location or BIM level, and correlation analysis is employed to determine whether higher complexity is correlated with higher BIM levels. To determine the ranking, compute the mean scores for each performance domain and BIM aspect using Likert scale ratings. Subsequently, arrange the scores in order of participant perceptions, from most effective to least effective.

3.5.2. Correlation Analysis

Spearman’s correlation coefficient was used to measure the strength and direction of linear relationships between BIM aspects and performance domains. A similar approach was used by Lee et al. (2021). In addition, it was determined whether there was a relationship between project complexity and BIM level across geographic locations.

Spearman’s correlation ρ was introduced by Charles Spearman in 1990. It is a numerical value between -1 and 1 that summarizes the characteristics of a dataset and indicates the direction and degree of interaction between variables.

Sign: The coefficient's sign indicates whether the variables are changing in unison or opposition.

A positive value indicates that the variables are changing in unison along the same path, while a negative value indicates that they are moving in the opposite direction. Table 7 below summarizes the interpretation of the correlation coefficient.

Table 7: Interpretation of Correlation Coefficients and Their Relationship Types

Correlation Coefficient	Type of Correlation	Interpretation
1	Perfect positive correlation	The other variables change in the same direction as the changed variable.
0	Zero correlation	The variables do not relate to one another.
-1	Perfect negative correlation	The other variables shift in the opposite direction when one variable changes.

Absolute value: The absolute value of a correlation coefficient also indicates the degree of a correlation; the correlation is stronger when the absolute value is higher (Asuero et al., 2006). The Table 8 below summarizes the strength and direction of correlations based on the value of ρ.

Table 8: Strength and Direction of Correlation Based on Spearman's

ρ Value	Strength	Direction
• More than 0.5 • Less than -0.5	Strong	Positive/Negative
• 0.3 to 0.5 • -0.3 to -0.5	Moderate	Positive/Negative
• 0 to 0.3 • 0 to -0.3	Weak	Positive/Negative
0	None	None

Below is a formula for calculating the Spearman correlation coefficient (ρ):

$$\boldsymbol{\rho = 1 - \frac{6\sum d_i^{\,2}}{n(n^2 - 1)}} \qquad (3\text{-}1)$$

Where:

- $\boldsymbol{\rho}$: Pearson correlation coefficient
- n: The number of paired observations in the dataset.
- d_i: diffrence between the two ranks of each observation

3.5.3. Ordinal Regression Analysis

Logistic regression was chosen in this study to fit the inherent classification of ordinal dependent variables and one or more independent variable measurement levels (Appendix A) without assuming that the differences are uniform or measurable on a continuous scale. The aim of using logistic regression is to analyze and study the impact of BIM aspects on performance domains . The general form of the ordinal logistic regression model is:

$$\boldsymbol{\log\left(\frac{P(Y \le j)}{P(Y > j)}\right) = \theta_j - (\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n)} \qquad (3\text{-}2)$$

Where:

- Y is the ordinal response variable.
- θ_j are the thresholds or cut-points.
- $\beta_1, \beta_2, \ldots, \beta_n$ are the coefficients for the predictor variables.
- $X_1, X_2, \ldots, X_n$ are the predictor variables.

3.5.3.1. Cumulative Logits

This model is concerned with cumulative probabilities rather than probabilities for separate categories, taking into account the probability of this event and all other events above it in the ordinal order. The model uses cumulative probabilities up to a certain threshold, thus transforming the range of ordinal classes into a binary comparison at each threshold.

The response Y is measured on a five-point Likert scale (1 = strongly disagree, 2 = disagree). 3 = Neutral 4 = agree 5 = strongly agree). The cumulative probabilities are denoted by *l1, ..., l4*, which are probabilities of a response being less than or equal to given category *j*.

the cumulative logits of *Y≤j* can be expressed as:

$$\boldsymbol{P(Y \leq j) = \pi_1 + \pi_2 + \cdots + \pi_j} \qquad \textbf{(3-3)}$$

Where π_j represent the probability of being in category j, so :

$$\boldsymbol{logit(P(Y \leq j))} = \left(\frac{\boldsymbol{P(Y \leq j)}}{\boldsymbol{P(Y > j)}}\right) \qquad \textbf{(3-4)}$$

$$= \log\left(\frac{\pi_1 + \pi_2 + \cdots + \pi_j}{\pi_{j+1} + \cdots + \pi_J}\right)$$

Moreover, $\pi_1 + \pi_2 + \cdots + \pi_j$ represent the probabilities associated with different categories or levels of the outcome variable Y, up to the level j.

Logit 1: Comparing "Strongly Disagree" vs. the rest:

$$\boldsymbol{logit(P(Y \leq 1)) = \log\left(\frac{P(Y \leq 1)}{P(Y > 1)}\right)} \qquad \textbf{(3-5)}$$

Logit 2: Comparing "Strongly Disagree" or "Disagree" vs. the rest:

$$\boldsymbol{logit(P(Y \leq 2)) = \log\left(\frac{P(Y \leq 2)}{P(Y > 2)}\right)} \qquad \textbf{(3-6)}$$

Logit 3: Comparing "Strongly Disagree," "Disagree," or "Neutral" vs. the rest:

$$\boldsymbol{logit(P(Y \leq 3)) = \log\left(\frac{P(Y \leq 3)}{P(Y > 3)}\right)} \qquad \textbf{(3-7)}$$

Logit 4: Comparing "Strongly Disagree," "Disagree," "Neutral," or "Agree" vs. "Strongly Agree":

$$\boldsymbol{logit(P(Y \leq 4)) = \log\left(\frac{P(Y \leq 4)}{P(Y > 4)}\right)} \qquad \textbf{(3-8)}$$

linear predictor in an ordinal logistic regression model:

$$\boldsymbol{l_i = \alpha_j + \beta_1 X_1 + \cdots + \beta_p X_p} \qquad \textbf{(3-10)}$$

Then the predictors are incorporated, the model become:

$$l_i = \alpha_j + \beta_{OIR}OIR + \beta_{AIR}AIR + \beta_{PIR}PIR + \beta_{EIR}EIR + \beta_{BIDE}BIDE + \beta_{BSCMM}BSCMM + \beta_{BQCV}BQCV + \beta_{BCC}BCC + \beta_{BTC}BTC \qquad 3\text{-}1)$$

$\pi_{j+1} + \cdots + \pi_J$: These represent the probabilities associated with the levels of Y greater than j, where J is the total number of levels of Y.

Lj: Logit of the cumulative probability $P(Y \leq j)$.
α_j: Intercept term for the jjjth logit.
$\beta_1, \ldots, \beta_p$: Coefficients for predictor variables $X_1, \ldots, X_p$.
$X_1, \ldots, X_p$: Predictor variables in the model.

This model is called the proportional odds(PO) by McCullagh (1980), Harrell (2015) stated that it is most useful in practice because simplicity of the interpretation. In this model, the regression coefficients represent the log odds of being at or above a particular category of the outcome, assuming that these odds are proportional across the different thresholds.

3.5.3.2. Estimation:

The likelihood function in ordinal regression is the product of the probabilities of observing the actual outcomes in the data, given the model parameters. While the log-likelihood function is the natural logarithm of the likelihood function. Taking the logarithm simplifies the product into a sum, making it easier to differentiate and maximize. In ultimate, the Log-Likelihood function quantifies how well the model explains the observed outcomes based on the predictors (BIM aspects) that are derived from the individual probability density functions; the expression is maximized to yield optimal values of β.

For a given observation *i* and category *j*, the probability of the observation falling into category j is π_{ik}.

The log-likelihood for a single observation *i* can be written as:

$$L(\pi_i y_i) = \sum_{j=1}^{J} y_{ik} \log(\pi_{ik}) \qquad (3\text{-}2)$$

The total log-likelihood considering all n observations, is the sum of the log-likelihoods for each individual observation:

$$\boldsymbol{L(\pi; y) = \sum_{i=1}^{n}\sum_{j=1}^{J} y_{ik} \log(\pi_{ik})} \qquad (3\text{-}3)$$

This function sums the contributions of each observation across all categories.

Aim of likelihood to compare models same data with adding or removing predictors variables to estimate optimal β (BIM aspects), the negative value closer to zero the better fit data well.

regression diagnostics

Regression diagnostics is a component that is designed to ascertain whether the calculated model and the assumptions we have made about the data and the model are consistent with the recorded data.

Ordinary Assumption:

i. Independence of coefficient from cut-off level j, which imply any BIM aspects on the odds of agreeing (versus disagreeing) with statement about performance domain is consistent among all cut-offs levels.
ii. There is no interaction between predictors and outcome Y
iii. Parallel slope assumption: Within framework of proportional odds model, if this assumption holds, the coefficient for each BIM aspects don't change with difference level of outcome Y, plotting the predicted logits for different categories can visually assess if the lines are parallel.

Goodness-of-fit test

i. Pseudo R-Square values are used to assess how well the model explains the variability in the data.

$$\boldsymbol{R^2 = 1 - \frac{L_{fitted}}{L_{null}}} \text{ 3-4)}$$

Where:

L_{fitted}: is the likelihood of the model being evaluated.

L_{null}: is the likelihood of a null model (a model without predictors)

Pseudo R-Square values generally do not reach 1, even for a well-fitting model. Cox and Snell approximate the R-Square by analogizing it to the one in linear regression; however, its maximal value may be less than 1.

Nagelkerke: Modifies Cox & Snell's measure to accommodate values of up to 1, thereby simplifying the interpretation process.

McFadden: Contrasts the log-likelihood of the fitted model with that of a null model.Pseudo R-Square values that are lower suggest that the model is not adequately explaining the data, while values that are higher suggest that the model is performing better.

ii. Deviance test: Compare the likelihood of fitted model to models that predict the observed data perfectly

$$D = 2 \sum y_{ik} \log \left(\frac{p_{ij}}{\pi_{ij}} \right) 3\text{-}5)$$

Where:

p_{ik}: observation proportion for i^th observation in the j^th category

π_{ij}: probability for i^th observation in the j^th category

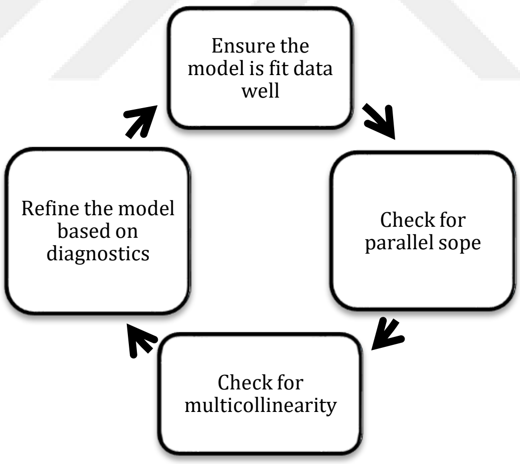
Higher deviance static and lower P-value suggest model not fit data well

Collinearity Diagnostics:

No multi-collinearity is a general assumption in any regression model. It ensures that the BIM aspects are not highly correlated with each other. The test begins by examining the correlation plot between each BIM aspect. The correlation plot can check if there is a strong linear relationship between the two variables; however, it is not that high to warrant a collinearity. Consequently, a variance inflation factor (VIF) test should be conducted to determine the presence of multi-collinearity. Because ordinal logistic regression models have a categorical dependent variable, VIF may not be appropriate. Categorical variables were either transformed into a numeric dummy variable or the model was run as linear regression to resolve this issue. The VIF test general rule of thumb is that multi-collinearity is present if the VIF value exceeds 10. The coefficient loses stability when collinearity is present, leading to statistically insignificant outcomes. The removal or combination of one of each correlated variable is used to address multi-collinearity.

Model refinement:

It is assumed that a four-stage iterative process is necessary to develop a model that generates dependable estimates and results. It initiates by verifying that the model corresponds with the data. Once the initial model is satisfactory, the subsequent phase involves verifying the consistency of the effect of each predictor on the probability of the higher versus lower classes across all samples of the ordinal result using the parallel test. After these aspects have been addressed, it is imperative to verify that the predictor variables are not correlated and do not exhibit multi-collinearity. From these diagnoses, the model is modified, approved, and the results are extracted.



4. IMPLEMENTATION AND RESULTS

4.1. Reliability Analysis

4.1.1. Cronbach's Alpha

Table 9: Item Analysis and Cronbach's Alpha for Performance and BIM Aspects

Item	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Stakeholder Satisfaction	63.8168	59.782	0.685	0.836
Team Collaboration	63.5115	66.698	0.386	0.852
Project Lifecycle Alignment	63.916	66.154	0.402	0.851
Strategic Planning Efficiency	63.5725	63.277	0.56	0.844
Project Operations Effectiveness	63.5115	65.006	0.529	0.846
Project Delivery Excellence	63.855	64.494	0.522	0.846
Metrics Tracking	63.8321	69.341	0.225	0.857
Uncertainty Management	63.7939	69.15	0.199	0.86
OIR	63.7481	66.021	0.44	0.849
AIR	63.7252	66.109	0.477	0.848
PIR	63.7634	64.259	0.573	0.844
EIR	64.0229	60.776	0.639	0.839
BIDE	63.8473	62.561	0.633	0.84
BAOL	63.8702	70.391	0.127	0.862
BSCMM	63.4733	63.697	0.598	0.842
BQCV	63.9313	64.141	0.478	0.848
BCC	63.5038	67.698	0.402	0.851
BTC	63.3511	68.291	0.306	0.855

Reliability analysis of the data using Cronbach's alpha revealed good internal consistency of 0.856 across 18 items (8 performance domains and 10 BIM aspects), Table 9 indicating that the items work reliably with a common structure. It can be noted that most of the items had corrected correlations higher than 0.3, which supports their consistency with the overall scale. However, some items showed lower correlations (Metrics Tracking, Uncertainty

Management, BAOL), indicating that they may not be consistent with other items. However, removing these items did not significantly improve the overall reliability and these items still contribute to the coherence of the scale.

4.1.2. Split-Half Reliability

Table 10: Reliability Statistics for Split-Half Reliability

Statistic	Value
Cronbach's Alpha (Part 1)	0.736
Number of Items (Part 1)	9
Cronbach's Alpha (Part 2)	0.768
Number of Items (Part 2)	9
Correlation Between Forms	0.728
Spearman-Brown Coefficient (Equal Length)	0.842
Spearman-Brown Coefficient (Unequal Length)	0.842
Guttman Split-Half Coefficient	0.842

To ensure the reliability of the measurements a different method was applied, split-half reliability was used. Table 10 indicates good consistency of the data with Spearman-Brown coefficient and Guttman coefficient of 0.842. The halves have acceptable Cronbach's alpha values of 0.736 and 0.768 with a correlation of 0.728, this correlation constitutes a strong agreement between the two halves.

4.2. Research Setting and Participants

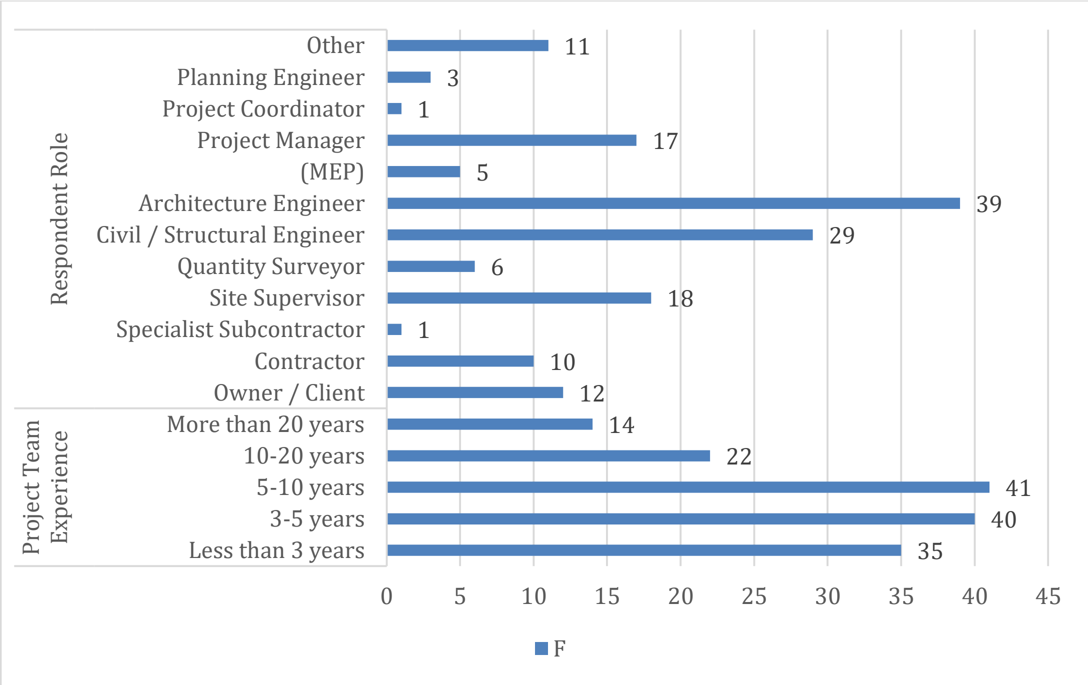


Figure 8: Distribution of Respondent Roles and Project Team Experience

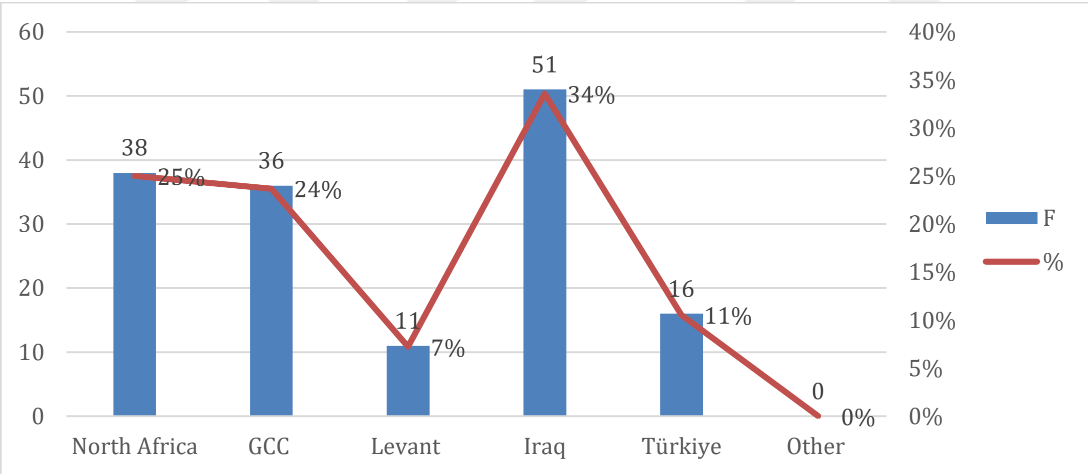


Figure 9: Geographical Distribution of Respondents and Their Percentage Representation

This study was conducted by distributing a questionnaire in the Middle East and North Africa region as shown in Figure 8, which included 153 participants involved in construction projects and who have an idea about the performance of various project performance domains. It should be noted that the questionnaire was not limited to those who have previous experience in using the BIM system in their operations to create an approximate picture of the percentage of participants in this system in the region.

The study revealed a diversity in the geographical distribution of the respondents, where Iraq had the highest representation, followed by the North African countries and the Gulf Cooperation Council countries, respectively. This indicates that the study may be a useful guide for those concerned with the construction field in this region. On the other hand, the Levant and Turkey were represented in a less varied way of participation in this study.

The project environment within the collected data showon in Figure 9 represents design and construction specializations in a predominant way. The table shows that the majority of the respondents are engineers in all design and technical specializations. With a noticeable presence from the operational and strategic perspective consisting of project managers and supervisors at a rate of 0.26%. In terms of experience, the largest group of respondents were those with experience between (5-10) years and (20-10) years, thus this combination of experience provides an acceptable ability and knowledge in respondents' opinions about the different performance domains and aspects of BIM.

4.3. Perceptions of Performance domain and BIM Aspects

Respondents' perceptions in Figure 10 of performance measures and BIM aspects were extracted representing five levels (strongly disagree, disagree, neutral, agree, strongly agree). The graph reveals high levels of positivity for domains such as project processes, team collaboration, and project life cycle alignment. In addition, respondents agreed on the effectiveness of uncertainty management and metrics tracking, despite some respondents remaining neutral or expressing disagreement. There is also some variation in the domains of stakeholders and excellence in project delivery, highlighting the need for continued efforts to enhance these aspects.

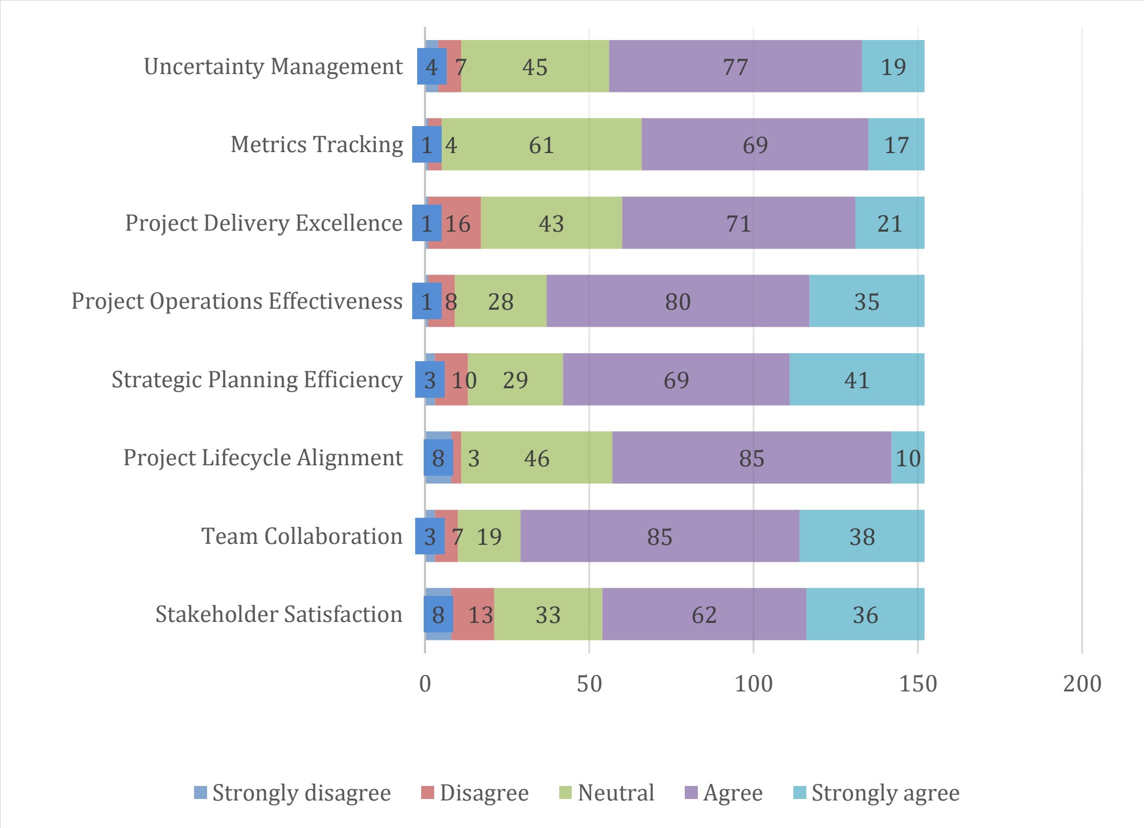


Figure 10: Respondent Perceptions of Performance Domains

Conversely, the distribution of BIM aspects in Figure 11 reveals a robust consensus in the BIM integration aspects, with a high degree of agreement. Additionally, the positive impact of BIDE and BAOL was generally agreed upon, with only a small number of respondents expressing neutrality toward these variables. This suggests that, even though these aspects were acknowledged as effective instruments in this research, there may be some ambiguity regarding the mechanism of their application or the extent to which they can be fully utilized. The distribution of opinions demonstrated the effectiveness of managing various types of information requirements in the context of requirements management. However, there is room for development, particularly in the area of information exchange requirements, where a small percentage of respondents expressed disagreement.

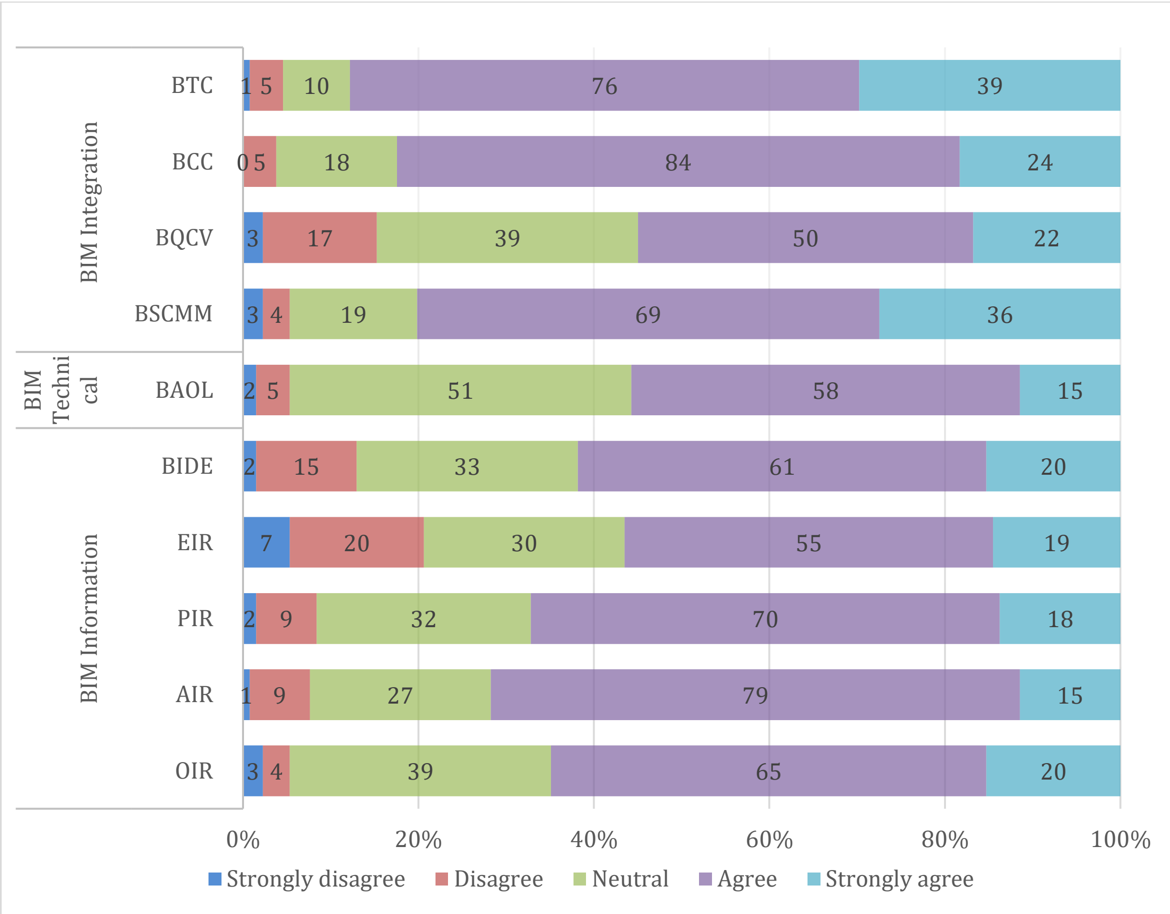


Figure 11: Resondent Perceptions of BIM Aspects

To analyze the data in more depth and to study whether there are significant differences between the variables, it is first necessary to examine them and determine whether they were taken from a normally distributed population by using the normality test (Kolmogorov-Smirnov and Shapiro-Wilk tests). All variables in the data showed Sig.=0.0000 which indicates a clear deviation from the normal distribution. Therefore, non-parametric statistical methods (Kruskal-Wallis and Chi-square tests) were used which do not assume normal distribution. For the test tables see the Appendix.

4.4. BIM Levels by Geographical Location and Project Team Experience

The current level of BIM practices may be significantly influenced by regional factors, as evidenced by the substantial disparity in BIM usage across geographic locations (p=0.008). Iraq and the Levant have the highest prevalence of BIM level 0, with this level being the most prevalent. Although North Africa and the GCC have a higher prevalence of BIM level 1 and level 2, this may be attributed to the countries' policies that encourage stakeholders to achieve high levels of BIM implementation and facilitate the adoption of the system. Conversely, Table 11 demonstrated a substantial disparity in project team experience (p=0.024). The distribution indicates that the most experienced teams (5-10) employ BIM level 2, while the least experienced teams (1-4) tend to employ BIM level 0 .as shown in Figure 12.

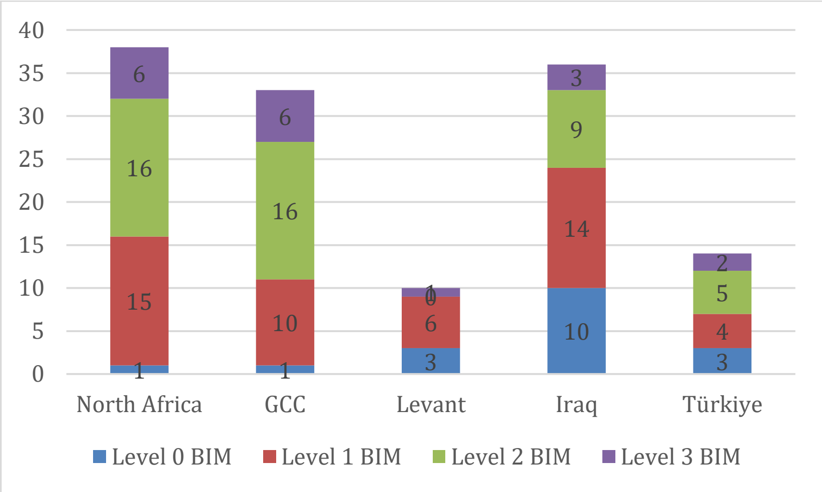


Figure 12: Geographical Distribution of BIM Levels

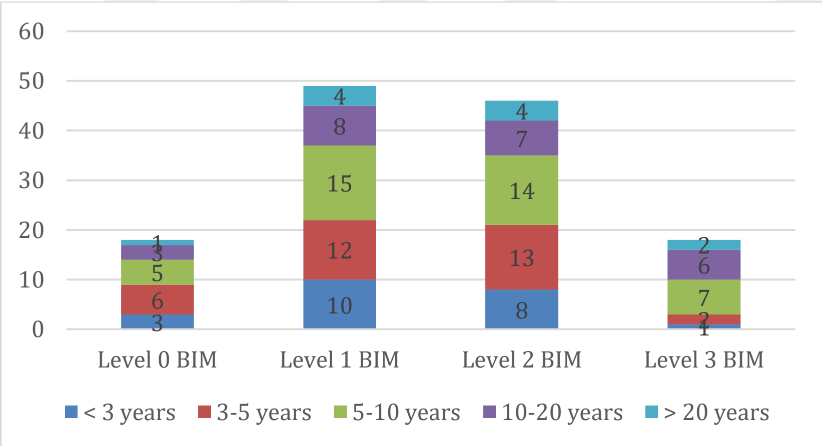


Figure 13: Project Team Experience and BIM Levels

Table 11: Kruskal-Wallis Test BIM Levels by Geographical Location and Team Experience

Variable	Kruskal-Wallis H	df	Asymp. Sig.
Geographical Location	11.956	3	0.008
Project Team Experience	9.414	3	0.024

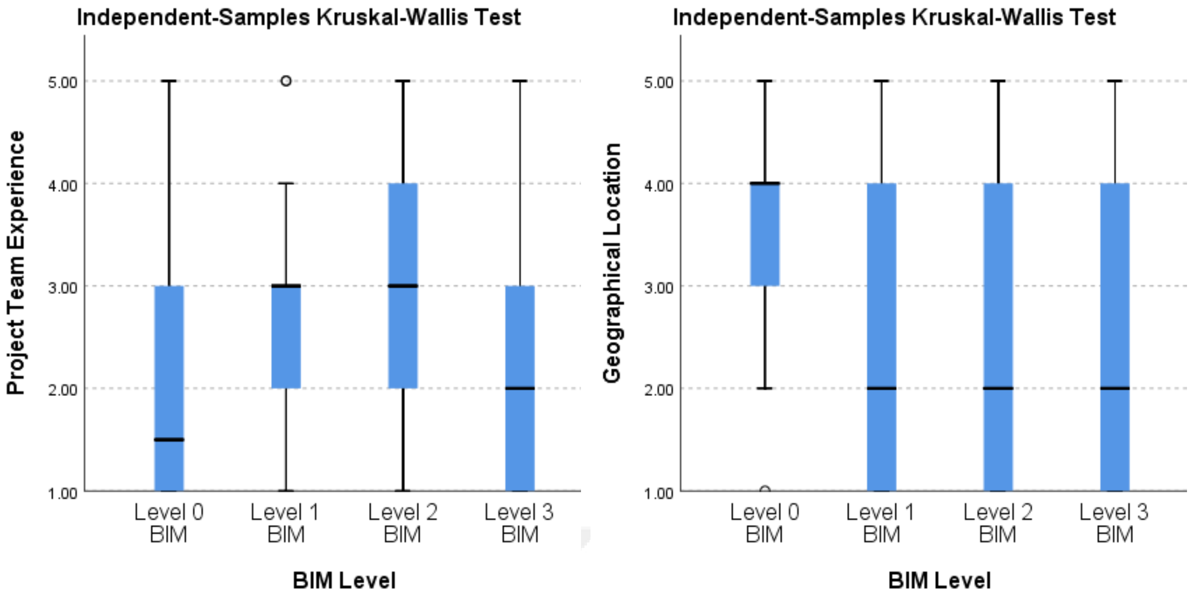


Figure 14: Boxplots showing the distribution of Project Team Experience (left) and Geographical Location (right) across different BIM Levels

Figure 14 demonstrate that Level 0 BIM exhibits a greater degree of variability in terms of both geographical locations and project team experiences. Specifically, the median experience levels are lower, while the median geographical adoption is higher. Conversely, the distributions of Levels 1, 2, and 3 are more consistent and restricted across regions, suggesting that they are used in a standardized manner. The median experience of the project team increases as the BIM levels increase, with the broadest spread occurring at Level 2, which suggests that a diverse range of experience levels are using more advanced BIM practices. In general, the adoption of advanced BIM levels is more consistent across locations, and the team's experience increases as the complexity of the project increases.

4.5. Project Complexity by Team Experience, and BIM Level

As shown in Table 12, p-values are 0.001 for project team experience and 0.041 for BIM level asymp. Sig. Given that both p-values are less than the generally accepted significance threshold of 0.05, this implies statistically significant variations among the several degrees of project complexity. Team experience distribution and BIM level adopted indicate interesting changes as project complexity increases. More complicated projects notably are more likely to be overseen by more seasoned teams and to use advanced BIM methodologies including BIM Level 2.. As for BIM levels, the test also shows a significant difference, as there is a tendency towards using higher BIM levels as the project complexity increases, especially at BIM level 2. as shown in Figure **16**.

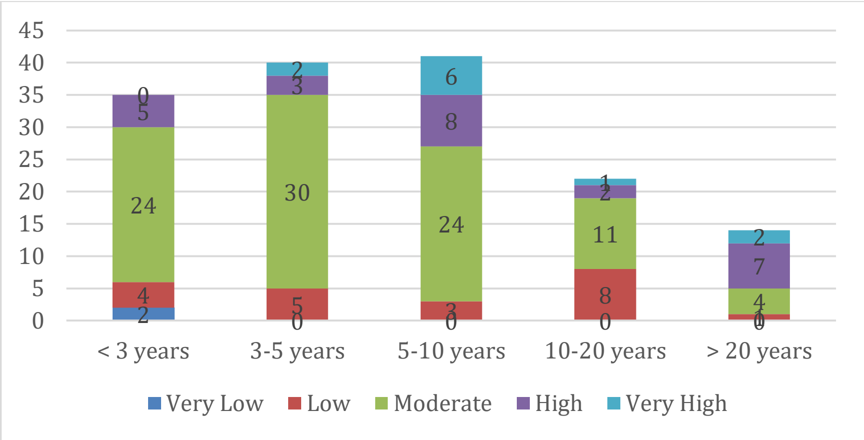


Figure 15: Project Team Experience Across Project Complexity

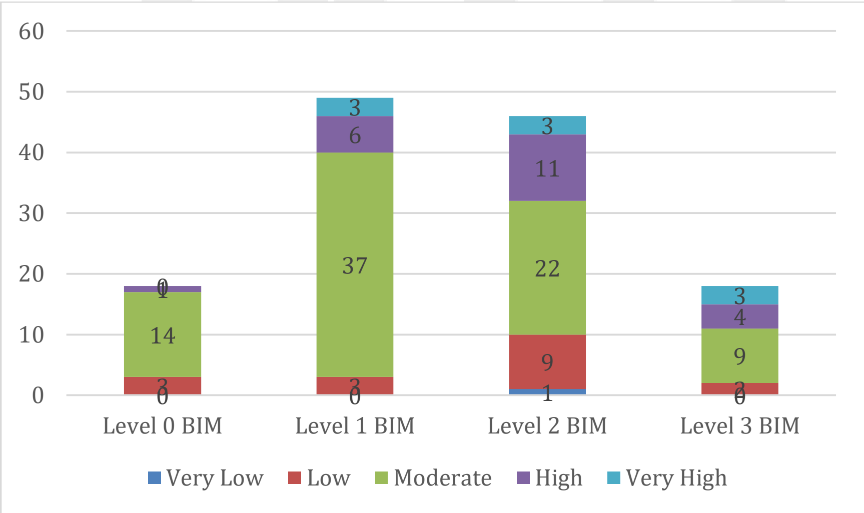


Figure 16**:** BIM Levels Across Project Complexity

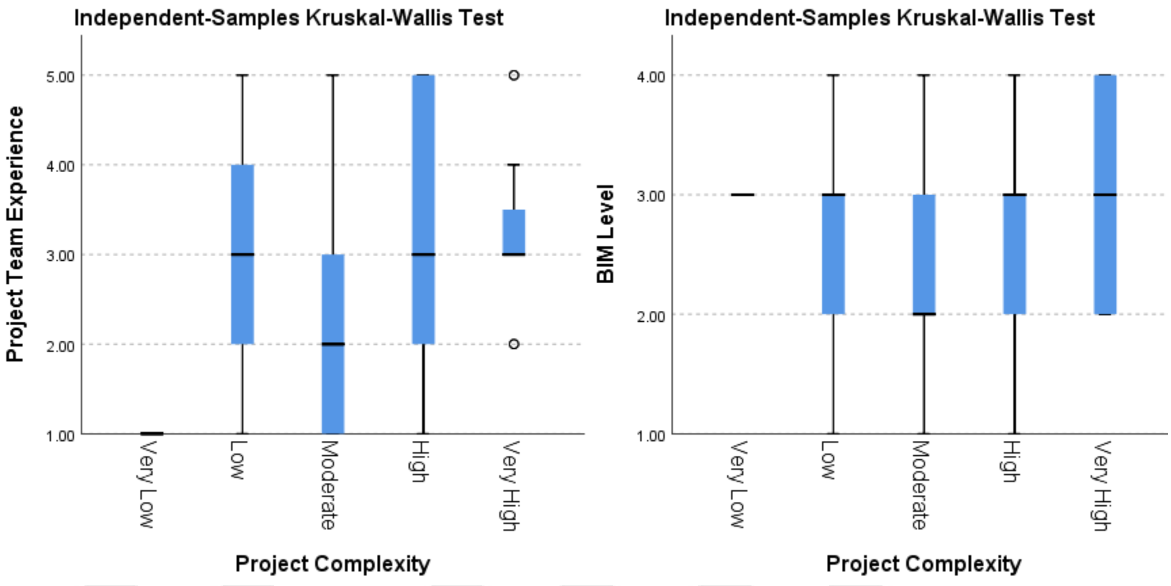


Figure 17: Project Complexity with Project Team Experience (left) and BIM Level (right)

The Figure 17 demonstrate the diversity in BIM Level usage and project team experience across various levels of project complexity. They emphasize that more intricate projects not only have a higher median team experience but also exhibit a larger degree of variability in both team experience and BIM Level usage. In particular, projects with a "Very High" level of complexity exhibit the broadest range of BIM Level usage, which suggests that the teams responsible for these projects have a greater amount of experience, potentially as a result of the challenges associated with managing complex projects.

Table 12: Kruskal-Wallis H: Project Complexity by Project Team Experience and BIM Level

	Project Team Experience	BIM Level
Kruskal-Wallis H	14.549	9.973
df	4	4
Asymp. Sig.	.006	.041

4.6. Prioritization of Performance Domains and BIM Aspects

Since the performance domains and BIM aspects are not normally distributed, they were classified using the Friedman test. The results showed the following:

The results as shown in Figure 18 reveal that some domains are considered more important than others with a Chi-square value of p=0.000. The team collaboration is the highest average, indicating that respondents believe that defining responsibilities and establishing a unified vision for the team should be a priority for effective project performance. The lowest ranking of the measurement tracking domain may be explained by the respondents' perception that they view it as a monitoring tool rather than a performance driver.

Figure 18: Radar Chart for performance domain

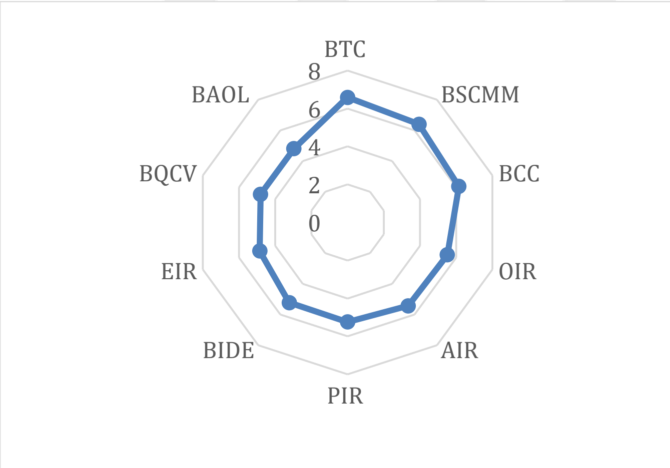


Figure 19: Radar Chart for BIM Aspects

On the other hand, the BIM aspects show a large variation with a Chi-square value of 79.512 and P=0.000, where the BIM training aspect ranked first, perhaps because this aspect can accelerate the adoption of BIM and expand its knowledge. Respondents may imagine that there should be experiential training lectures that simulate the collaboration between the different BIM roles and how to manage information between different disciplines. In contrast, the analysis and improvement aspects were ranked at the lowest level, perhaps because companies do not follow a single, interoperable standard, especially in complex projects.

4.7. Correlation Analysis of BIM Aspects

Table 13: Spearman's Correlation Coefficients for BIM Aspects

	OIR	AIR	PIR	EIR	BIDE	BAOL	BSCMM	BQCV	BCC	BTC
OIR	1.00	0.15	0.13	0.28	0.47	0.004	0.211	0.25	0.17	-0.002
AIR		1.00	0.39	0.37	0.28	0.245	0.363	0.21	0.22	-0.030
PIR			1.00	0.30	0.45	-0.022	0.336	0.25	0.27	0.231
EIR				1.00	0.38	0.165	0.313	0.32	0.10	-0.089
BIDE					1.00	-0.169	0.459	0.45	0.34	0.214
BAOL						1.000	0.094	0.23	0.13	-0.034
BSCMM							1.000	0.36	0.27	0.325
BQCV								1.00	0.52	0.216
BCC									1.00	0.513
BTC										1.00

Table 13 indicates that there are significant and variable degrees of interrelationships between various BIM aspects. The observations of strong positive correlations (r > 0.5) between BIDE and OIR (r =.473) and between BIM BCC and BTC (r =.513) suggest that efficient information delivery and effective collaboration are essential for the accurate provision of information to the various business functions, thereby facilitating well-informed decision-making and effective asset management throughout their lifecycle. Aspects such as PIR are correlated with BIDE (r =.456) and BSCMM (r =.336), indicating that project business cases, strategic documents, project stakeholders, and project tasks are moderately associated with cost management and information efficiency (r = 0.3 to 0.5). In contrast, BAOL exhibits only modest correlations with other aspects, particularly with BIM BQCV (r =.235), underscoring its limited integration into current BIM processes.

Table 14: Significance Levels of Spearman's Correlation Coefficients

	OIR	AIR	PIR	EIR	BIDE	BAOL	BSCMM	BQCV	BCC	BTC
OIR	-	0.081	0.133	0.001	0.000	0.965	0.016	0.003	0.046	0.982
AIR		-	0.000	0.000	0.001	0.005	0.000	0.015	0.009	0.730
PIR			-	0.000	0.000	0.801	0.000	0.004	0.001	0.008
EIR				-	0.000	0.059	0.000	0.000	0.248	0.310
BIDE					-	0.054	0.000	0.000	0.000	0.014
BAOL						-	0.286	0.007	0.116	0.699
BSCMM							-	0.000	0.001	0.000
BQCV								-	0.000	0.013
BCC									-	0.000
BTC										-

Table 14 represents the significance of Spearman correlation coefficients. Significant p-values (<0.05) are indicated in shades of green.

Assessing information management practices and their delivery mechanisms (BIDE) is essential for fulfilling organizational information requirements (OIR), project information requirements (PIR), and managing project costs and resources. Information distribution templates delineate accountability for each particular information product and synchronize these plans with design and construction programs.

The robust correlation between effective training, collaboration, and communication within a BIM system elucidates the evidence that enhanced BIM training results in improved collaboration and communication.

The connections between PIR and BSCMM suggest that projects with well articulated requirements generally exhibit superior performance in cost and resource management. This relationship is elucidated by the clear definition and efficient administration of project execution reports and information delivery essential for attaining strategic objectives, hence facilitating more precise planning and budget management. The robust positive association between BCC and BQCV indicates that increased collaboration enhances the likelihood of the project fulfilling quality standards. The research indicates that quality control relies on precise and consistent data, effective interdepartmental communication, and alignment among all team members. Weak correlations in the technical BIM dimensions (BAOL), which encompass BIM analyses for identifying conflicts among models across disciplines, suggest insufficient integration with other components. This signifies that the technical BIM functionalities are not being sufficiently employed.

4.8. Ordinal Logistic Regression Implementation

The purpose of generating ordinal regression models in this research is to investigate the mechanism of influence of different BIM aspects on performance domains, specifically to verify whether these aspects increase the likelihood of higher satisfaction levels in different performance domains within MENA projects.

4.8.1. Model development and selection process

To obtain independent and objective effects on project performance domains, following observations were noted:

The stepwise forward regression method was applied manually, where predictors were added one by one until the ten BIM aspects were included. Then, predictors that have no effect on the model are removed. When removing predictors, the suitability of the data to the generated model must be taken into consideration and the assumptions of multi-collinearity and relative probabilities are not violated. In addition, Pearson's chi-square was ignored because it does not take into account the normal distribution to interpret the response, especially if the variables are ordinal. On the other hand, it should be noted that the model is chosen by comparing -2log-likelihood and taking the lower value indicating that it is more suitable for the data than the rest of the models.

4.8.2. Results for eeach performance domain

4.8.2.1. Stakeholder satisfaction performance domain:

Table 15: Logistic Regression Analysis for Stakeholder Satisfaction

Category	Measure	Estimate	SE	p-value	Odds Ratio	Tolerance(VIF)
Threshold	Category = 1	5.147	1.299	0.000	-	-
	Category = 2	7.062	1.349	0.000	-	-
	Category = 3	9.242	1.482	0.000	-	-
	Category = 4	12.161	1.616	0.000	-	-
(Predictors)						
	EIR	0.947	0.202	0.000	2.58	0.751 (1.331)
	BIDE	1.219	0.261	0.000	3.38	0.619 (1.616)
	BSCMM	0.72	0.241	0.003	2.05	0.749 (1.335)
	BQCV	0.55	0.237	0.020	1.73	0.587 (1.704)
	BCC	-0.611	0.307	0.046	0.54	0.729 (1.373)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		202.406	227	0.878		
Pseudo R-Square		**Measure**	**Value**			
		Cox	0.573			
		Nagelkerke	0.609			
		McFadden	0.302			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		23.578	15	0.073		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		
Intercept Only	332.264					
Final Model	220.922	111.342	5	0.000		

Table 15 demonstrated Thresholds indicate the cut-off points for moving between different categories of stakeholder satisfaction. They show an apparent gradual increase as satisfaction levels move from strongly disagree to strongly agree. This suggests that a greater estimated value is required to move to the next category as you move to higher satisfaction levels. The predictors provide their impact on stakeholder satisfaction levels. The BIDE predictor, the most influential predictor, has an estimate of 1.219 at a p-value of 0.000, indicating that a

3.38 increase in this index increases the probability of higher satisfaction. It is succeeded by the BSCMM, EIR, and BQCV predictors in that order. Each increase in these predictors increases stakeholder satisfaction. In contrast, the BCC predictor had a negative effect with an odds ratio of 0.54, indicating that an increase in this predictor reduces the likelihood of achieving a higher level of stakeholder satisfaction. A high p-value for the Deviance Test (0.878>0.05) indicates that the model fits the observed data well. This shows that the predictors adequately explain the variance without significant deviation. The predictors in the model represent 60.9% of the variance in stakeholder satisfaction, as indicated by the pseudo R2 values, which indicate a moderate to solid variance. The p-value (0.0737>0.05) indicates evidence that the parallel lines assumption is not violated, indicating that each predictor is consistent across all thresholds. When predictors are included, the log-likelihood value suggests that the model is more well-fitted, representing a substantial decrease compared to the log-likelihood of the intercept with p-values < 0.05.

4.8.2.2. Team performance domain

Table 16: Logistic Regression Analysis for Team Performance

Category	Measure	Estimate	S E	p-value	Odds Ratio	Tolerance(VIF)
Threshold	Category = 1	-1.432	1.363	0.294	-	-
	Category = 2	0.110	1.274	0.931	-	-
	Category = 3	1.424	1.273	0.263	-	-
	Category = 4	5.018	1.353	0.000	-	-
Location (Predictors)						
	EIR	1.115	0.197	0.000	3.050	0.979 (1.022)
	BCC	-1.074	0.326	0.001	0.342	0.759 (1.317)
	BTC	0.919	0.284	0.001	2.507	0.773 (1.294)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		113.143213	105	0.276		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.284			
		Nagelkerke	0.320			
		McFadden	0.153			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		5.546	9	0.784		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		

Intercept Only	187.254			
Final Model	145.019	42.234	3	0.000

Table 16 explains the thresholds represent the cut-off points between different team performance categories; they show an apparent incremental rise, especially at Category 4, which has a significant estimate of 5.018 (p-value = 0.000). This suggests that a higher estimated value is necessary to move to the higher team performance categories. Regarding the predictors, EIR emerges as the most influential predictor with an estimate of 1.115 and a p-value of 0.000, indicating that for every unit increase in EIR, the odds of reaching a higher team performance category increase by a factor of 3.05. The odds ratio of 2.507 and an estimate of 0.919 (p-value = 0.001) for BTC indicate that an increase in this predictor increases the likelihood of attaining a higher team performance level. Conversely, BCC has a negative effect, with an estimate of -1.074 (p-value = 0.001) and an odds ratio of 0.342. Increased BCC levels reduce the likelihood of improved team collaboration. The Deviance Test shows a well-fitted model with a high p-value (0.276 > 0.05). The pseudo-R^2 indicates that the model accounts for approximately 32% of the variance in team performance, suggesting a moderate explanatory power. Additionally, the p-value of the Test of Parallel Lines (0.784 > 0.05) supports the parallel lines assumption, indicating that each predictor's effect is consistent across all thresholds. The substantial decrease in the -2 Log Likelihood value from the intercept-only model 187.254 to the final model 145.019 further confirms the improved model fit, as evidenced by the (p-value < 0.05).

4.8.2.3. Project life cycle performance domain

Table 17: Logistic Regression Analysis for project life cycle

Category	**Measure**	**Estimate**	**S E**	**p-value**	**Odds Ratio**	**Tolerance(VIF)**
Threshold	Category = 1	0.553	1.011	0.584	-	-
	Category = 2	0.983	1.003	0.327	-	-
	Category = 3	3.117	1.046	0.003	-	-
	Category = 4	6.783	1.168	0.000	-	-
(Predictors)						
	OIR	0.082	0.236	0.729	1.085	0.766 (1.306)
	PIR	0.659	0.244	0.007	1.933	0.748 (1.337)
	EIR	0.805	0.201	0.000	2.237	0.734 (1.363)
	BIDE	-0.486	0.246	0.048	0.615	0.592 (1.690)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		

Deviance Test (Chi-Square)		207.391	180	0.079
Pseudo R-Square		**Measure**	**Value**	
		Cox and Snell	0.194	
		Nagelkerke	0.218	
		McFadden	0.098	
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**
		0.167	12	1
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**
Intercept Only	253.515			
Final Model	225.291	28.225	4	0.00001

Table 17 shows an increase in the threshold between Category 3 and Category 4, indicating that moving to higher levels of the project life cycle requires increasingly larger estimated values. The most influential factor is EIR, which indicates that the likelihood of achieving a higher level of project life cycle alignment increases by a factor of 2.237 for each unit increase in EIR. PIR follows with an odds ratio of 1.933. While BIDE shows a negative effect with a p-value of 0.048, which is close to the 0.05 threshold. While it does indicate statistical significance and an odds ratio of 0.615, suggesting that an increase in BIDE reduces the likelihood of achieving a higher category in project life cycle performance. However, OIR does not exhibit a statistically significant impact, as indicated by its p-value (0.729 > 0.05). The Deviance Test (p-value 0.079 > 0.05) indicates a fairly decent model fit. Also pseudo-R-square values suggest that the model explains about 21.8% of the variance, indicating a modest level of explanatory power. The parallel lines test is not violated, as evidenced by the p-value of 1, which indicates that the predictors are consistent across all thresholds. The inclusion of predictors results in a more favorable fit, as demonstrated by the highly significant p-value (< 0.05), which decreases the -2 log-likelihood from 253.515 in the intercept-only model to 225.291 in the final model.

4.8.2.4. Planning performance domain

Table 18: Logistic Regression Analysis for planning performance

Category	Measure	Estimate	S E	p-value	Odds Ratio	Tolerance(VIF)
Threshold	Category = 1.00	6.210	1.567	0.000	-	-
	Category = 2.00	8.306	1.604	0.000	-	-
	Category = 3.00	10.074	1.677	0.000	-	-

	Category = 4.00	12.960	1.823	0.000	-	-
(Predictors)						
	OIR	0.874	0.231	0.000	2.396	.863 (VIF:1.159)
	AIR	0.092	0.240	0.702	1.096	.814 (VIF:1.229)
	EIR	0.843	0.190	0.000	2.323	.815 (VIF:1.227)
	BCC	0.658	0.302	0.03	1.931	.692 (VIF:1.444)
	BTC	0.599	0.256	0.019	1.820	.757 (VIF:1.322)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		195.227	215	0.829		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.417			
		Nagelkerke	0.452			
		McFadden	0.211			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		13.795	15	0.541		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		
Intercept Only	284.895					
Final Model	214.182	70.713	5	0.0000		

The Table 18 indicates that boundaries between the categories in this model were well represented, as all thresholds showed statistically significant values, with increasing estimated values. Respondents tended to agree with their opinion on planning effectiveness. According to the predictors, the odds of attaining a higher level in the planning performance domain increase by 2.396 for every unit increase in OIR. Similarly, EIR exhibits a substantial positive effect, with an odds ratio of 2.323. The odds ratios of 1.931 and 1.820, respectively, suggest that increases in these variables are associated with improved planning performance. This is followed by BCC and BTC. Conversely, AIR does not significantly influence the efficacy of planning (p-value = 0.702). The model's pseudo-R-square values indicate that it explains approximately 45.2% of the variance in the planning performance domain, indicating a moderate explanatory power. Additionally, the result of the Test of Parallel Lines (p-value = 0.541 > 0.05) suggests that the assumption of parallel lines is not violated, which confirms that the predictors' effects are consistent across all thresholds.

4.8.2.5. Project work performance domain

Table 19: Logistic Regression Analysis for project work performance

Category	Measure	Estimate	S E	p-value	Odds Ratio	Tolerance(VIF)
Threshold	Category = 1.00	1.974	1.599	0.217	-	-
	Category = 2.00	4.979	1.407	0.000	-	-
	Category = 3.00	7.757	1.520	0.000	-	-
	Category = 4.00	11.095	1.656	0.000	-	-
(Predictors)						
	EIR	0.419	0.185	0.023	1.520	(0.862)1.16
	BAOL	0.907	0.246	0.000	2.477	(0.960)1.042
	BSCMM	1.769	0.295	0.000	5.865	(0.695)1.438
	BTC	-0.587	0.266	0.027	0.556	(0.793)1.261
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		196.986	196	0.467		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.45			
		Nagelkerke	0.498			
		McFadden	0.255			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		0.058	12	1		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		
Intercept Only	287.122		4	0.000		
Final Model	208.847	78.276				

Table 19 indicated that the transition between strongly disagree and disagree was not statistically significant compared to the rest of the categories that showed effectiveness in responding. Among the predictors, BSCMM stands out as the most influential, suggesting that a unit increase in BSCMM raises the odds of reaching a higher level of project work performance by a factor of 5.865. BAOL has a likelihood ratio of 2.477, indicating a positive impact. EIR makes a positive contribution, with a p-value of 0.023 and an estimate of 0.419. This implies that the probability of achieving a higher category increases by 1.520 for each unit increase in EIR. In contrast, BTC has a negative effect, with an estimate of -0.587 and a p-value of 0.027, suggesting that an increase in BIM training and competence reduces the likelihood of reaching a higher project work performance category, as reflected by its odds ratio of 0.556. The model's fit to the data is demonstrated by the Deviance Test (p-value =

0.467 > 0.05). The pseudo-R-square values suggest that the model has moderate explanatory power, as it explains 49.8% of the variance in project work performance. The p-value of 1 indicates the predictors' consistency across all thresholds, as it does not violate the parallel line assumptions. Furthermore, the inclusion of predictors leads to a more favorable model fit, as evidenced by the substantial decrease in the -2 log likelihood value from 287.122 in the intercept-only model to 208.847 in the final model (p-value < 0.05).

4.8.2.6. Project delivery performance domain

Table 20: Logistic Regression Analysis for project delivery performance

Category	**Measure**	**Estimate**	**S E**	**p-value**	**Odds Ratio**	**Tolerance(VIF)**
Threshold	Category = 1	-0.559	1.292	0.665	-	-
	Category = 2	2.521	0.991	0.011	-	-
	Category = 3	4.469	1.038	0.000	-	-
	Category = 4	6.877	1.123	0.000	-	-
Location (Predictors)						
	PIR	0.954	0.216	0.000	2.596	0.951
	OIR	0.350	0.205	0.087	1.419	0.951
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		70.849	50	0.028		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.189			
		Nagelkerke	0.205			
		McFadden	0.082			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		12.479	6	0.052		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		
Intercept Only	143.662		6			
Final Model	116.195	27.467	2	0.000		

As in the measurement performance domain model, the thresholds showed clear significance and effectively distinguished between 2, 3, and 4. This indicates that for every unit increase in PIR, the odds of reaching a higher level of project delivery performance increase by a factor of 2.596.OIR also indicates a positive impact, albeit less apparent, with an estimate of 0.350 and a p-value of 0.087. This suggests that OIR may enhance project delivery performance, although its impact is not statistically significant, as the p-value is marginally greater than 0.05. The goodness-of-fit for this model, as indicated by the Deviance Test (p-value = 0.028 < 0.05), suggests that there might be some domains where the model does not perfectly fit the data. The pseudo-R-square values indicate that the model represents approximately 20.5% of the variance in project delivery performance, reflecting a modest level of explanatory power. The Test of Parallel Lines (p-value = 0.052) indicates that the model's assumption of parallel lines is almost met, suggesting that the predictors are reasonably consistent across all thresholds. Additionally, the inclusion of predictors results in a better fit of the model, as shown by the decrease in the -2 Log Likelihood value from 143.662 in the intercept-only model to 116.195 in the final model (p-value < 0.05).see Table 20.

4.8.2.7. Measurement performance domain

Table 21: Logistic Regression Analysis for measurment performance

Category	Measure	Estimate	S E	p-value	Odds Ratio	Tolerance(VIF)
Threshold	Category = 1	1.171	1.485	0.43	-	-
	Category = 2	3.02	1.213	0.013	-	-
	Category = 3	6.919	1.364	0.000	-	-
	Category = 4	9.987	1.504	0.000	-	-
(Predictors)						
	AIR	1.18	0.273	0.000	3.254	0.863 (VIF = 1.159)
	OIR	-0.567	0.238	0.017	0.567	0.824 (VIF = 1.214)
	BSCMM	0.716	0.249	0.004	2.046	0.731 (VIF = 1.369)
	BQCV	0.573	0.206	0.005	1.774	0.796 (VIF = 1.256)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		164.587	200	0.968		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.341			
		Nagelkerke	0.381			
		McFadden	0.186			
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**		
		13.717	12	0.319		
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**		
Intercept Only	241.280					
Final Model	186.734	54.546	4	0.000		

Table 21 showed that AIR suggests a substantial positive influence. The odds ratio of 3.254 indicates that the probability of attaining a higher level of measurement performance increases by more than three times for each unit increase in AIR. In addition, the predictor

BSCMM has a positive impact, with an estimate of 0.716 and a p-value of 0.004. This suggests that a unit increase in BSCMM increases the probability of achieving a higher measurement performance level by a factor of 2.046. Following closely, BQCV has an estimate of 0.573 (p-value = 0.005) and an odds ratio of 1.774, indicating a positive impact on the performance domain. Nevertheless, a negative impact is suggested by a p-value of 0.017 and an estimate of -0.567 for OIR. The odds ratio of 0.567 suggests that the likelihood of attaining a higher measurement performance category decreases as OIR increases. The Deviance Test has confirmed the model's goodness-of-fit (p-value = 0.968 > 0.05), indicating that the observed data is well-fitted by the model. The pseudo-R-square values suggest that the predictors account for 38.1% of the variance in measurement performance, which is considered moderate. The parallel lines assumption is not violated, as evidenced by the Test of Parallel Lines (p-value = 0.319 > 0.05), which suggests that the predictors are consistent across all thresholds. As demonstrated by the decrease in the -2 Log Likelihood value from 241.280 in the intercept-only model to 186.734 in the final model (p-value < 0.05), the incorporation of predictors leads to a more accurate model fit.

4.8.2.8. Uncertainty performance domain

Table 22: Logistic Regression Analysis for uncertainty performance

Category	**Measure**	**Estimate**	**S E**	**p-value**	**Odds Ratio**	**Tolerance(VIF)**
Threshold	Category = 1.00	-2.528	1.363	0.064	-	-
	Category = 2.00	-1.13	1.315	0.39	-	-
	Category = 3.00	1.69	1.359	0.214	-	-
	Category = 4.00	5.307	1.395	0.000	-	-
(Predictors)						
	PIR	1.158	0.265	0.000	3.183	0.862 (VIF = 1.160)
	EIR	0.817	0.207	0.000	2.263	0.727(VIF = 1.375)
	BSCMM	-0.862	0.275	0.002	0.422	0.643 (VIF = 1.555)
	BQCV	-1.338	0.241	0.000	0.262	0.790 (VIF = 1.266)
	BTC	0.555	0.269	0.039	1.741	0.805 (VIF = 1.242)
	OIR	0.378	0.24	0.115	1.45	0.814 (VIF = 1.228)
Goodness-of-Fit		**Chi-Square**	**df**	**p-value**		
Deviance Test (Chi-Square)		222.637	262	0.963		
Pseudo R-Square		**Measure**	**Value**			
		Cox and Snell	0.401			
		Nagelkerke	0.442			

		McFadden	0.216	
Test of Parallel Lines		**Chi-Square**	**df**	**p-value**
-2 Log Likelihood		**Chi-Square**	**df**	**p-value**
Intercept Only	298.100	22.002	18	0.232
Final Model	230.942			

The insignificant p-values of categories 1, 2, and 3 inTable 22 present a challenge for the model in distinguishing between themselves. The model's ability to differentiate between category 4 and higher is demonstrated by the fact that category 4 is highly significant (p = 0.000). The likelihood of uncertainty management increases by threefold for each unit increase in PIR, as evidenced by an estimate of 1.158, a p-value of 0.000, and an odds ratio of 3.183. PIR had the most significant positive impact.EIR follows, with a positive effect size (estimate = 0.817, p-value = 0.000), indicating that a unit increase in EIR increases the odds of higher performance by a factor of 2.263.BTC has a positive effect with an odds ratio of 1.741 (p-value = 0.039), whereas OIR has a marginally non-significant effect (estimate = 0.378, p-value = 0.115). The odds ratio of 0.422 and an estimate of -0.862 (p-value = 0.002) suggest that the likelihood of achieving a higher level of uncertainty decreases as BSCMM increases. In the same vein, BQCV has an odds ratio of 0.262, which suggests a significant negative effect. The estimate is -1.338, and the p-value is 0.000. The Deviance Test indicates that the model is well-fitting the data and that there are no discernible deviations, as evidenced by a p-value of 0.963 > 0.05. The pseudo-R-square values indicate that the model explains a moderate 44.2% uncertainty performance variance.

4.9. Discussion and Comparative Analysis

The findings across a variety of performance domains consistently demonstrate that project requirements and BIM integration variables have a positive impact, while some variables have a negative impact. OIR has a positive impact on planning performance but a negative impact on measurement performance, due to the potential for data management deficiencies as it often involves managing large amounts of information, and not managing it effectively leads to inconsistencies in the quality and effectiveness of data measurement (Succar et al., 2012).On the other hand, AIR had the largest and only impact on measurement, which is obvious as it provides detailed information on monitoring asset usage, energy consumption, and operating costs (Kemp OBE, 2021). The project work cases, strategic brief, and project tasks contained in PIR demonstrated a significant positive impact on the development approach, life cycle, project delivery, and uncertainty performance. The results also showed that EIR has a positive impact because it represents and identifies the information required in each information exchange and sets expectations between stakeholders and delivery teams. The comparison of the various aspects of BIM integration revealed that BSCMM had a beneficial effect on stakeholder satisfaction, project work, and measurement performance. Nevertheless, it demonstrated a detrimental effect on uncertainty as a result of the potential rigidity or limited adaptability of the cost management system used by the target audience within the BIM system. The dual effects of BTC in the implementation of training were also emphasized in the majority of domains. It has the potential to significantly enhance team performance, planning, and uncertainty management, while its adverse effects on project work must be mitigated. Gerges et al. (2017) identify the absence of competent professionals who have received sufficient BIM training as one of the primary obstacles. The research indicated that 34.89% of respondents were self-taught, with the majority of professionals comprehending only the various BIM tools but not the entire process. This underscores the necessity of a strategic and context-specific approach to BIM implementation to guarantee the effective utilization of all performance domains. BCC can significantly enhance planning performance but has a negative impact on stakeholder satisfaction and team performance, which may be due to challenges in increased communication burden and lack of compatibility between products based on standards such as IFC. The proportionate odds assumption is generally supported by deviation tests, which indicate a satisfactory model fit. The models' explanatory power was poor to moderate, as evidenced by Nagelkerke R2 values that ranged from 20% to nearly 57%.

Table 23: Summary of Hypotheses Testing Results for BIM Impact on Performance Domains

Performance Domain	Hypothesis	Predictors	P-Value	null
Stakeholders	H0.1a BIM's information management	EIR, BIDE	$p < 0.05$	**Reject**
	H0.2a BIM's technical execution		N/A	**Fail to Reject**
	H0.3a BIM's integration	BSCMM, BQCV, BCC	$p < 0.05$	**Reject**
Team	H0.1b BIM's information management	EIR	$p < 0.05$	**Reject**
	H0.2b BIM's technical execution		N/A	**Fail to Reject**

	H0.3b BIM's integration	BTC, BCC, BIDE	$p < 0.05$	**Reject**
Development Approach and Lifecycle	H0.1c BIM's information management	PIR, EIR, BIDE	$p < 0.05$	**Reject**
	H0.2c BIM's technical execution		N/A	**Fail to Reject**
	H0.3c BIM's integration		N/A	**Fail to Reject**
Planning	H0.1d BIM's information management	OIR, EIR	$p < 0.05$	**Reject**
	H0.2d BIM's technical execution		N/A	**Fail to Reject**
	H0.3d BIM's integration	BCC, BTC	$p < 0.05$	**Reject**
Project Work	H0.1e: BIM's information management	EIR	$p < 0.05$	**Reject**
	H0.2e: BIM's technical execution	BAOL	$p < 0.05$	**Reject**
	H0.3e: BIM's integration	BSCMM, BTC	$p < 0.05$	**Reject**
Delivery	H0.1f: BIM's information management	PIR	$p < 0.05$	**Reject**
	H0.2f: BIM's technical execution		N/A	**Fail to Reject**
	H0.3f: BIM's integration		N/A	**Fail to Reject**
Measurement	H0.1g: BIM's information management	AIR,OIR	$p < 0.05$	**Reject**
	H0.2g: BIM's technical execution		N/A	**Fail to Reject**
	H0.3g: BIM's integration	BSCMM, BQCV	$p < 0.05$	**Reject**
Uncertainty	H0.1h: BIM's information management	PIR, EIR	$p < 0.05$	**Reject**
	H0.2h: BIM's technical execution		N/A	**Fail to Reject**
	H0.3h: BIM's integration	BSCMM, BQCV, BTC	$p < 0.05$	**Reject**

The rejected hypotheses in Table 23 represent strong statistical evidence (p-value < 0.05) that the predictor significantly affects the performance domain. Scientifically, emphasizing improvements in BIM variables that showed a significant effect (either positive or negative) may affect the performance results in the related domain. On the other hand, failure to reject the hypothesis indicates that the effect was not statistically significant in this study or may require further investigation into whether there are other factors that may have a more significant effect. Rejecting all null hypotheses of information management across all domains confirms its effective role in project success. Construction companies in the MENA should focus on defining project requirements within specific criteria. Although the conflicting results for integration practices suggest that their efficacy is context-dependent. In order to enhance integration practices, it is imperative to focus on the development of effective protocols, training programs, and tools, as well as the establishment of a balance between the preservation of essential standards and the ability to adapt to uncertainties. This will facilitate collaboration and communication (BCC). In domains that directly affect project work performance (BAOL), organizations should cultivate a culture of continuous learning when it comes to technical execution.

5. Conclusion

This study aims to investigate the impact of BIM on project performance domains within construction projects in the MENA region. Each of the different aspects of BIM, including information management, integration, and technical implementation, was investigated in the eight performance domains. The study used a methodological framework that combines descriptive statistics, correlation analysis, and ordinal regression to explore the relationships between BIM aspects and performance domains. Descriptive statistics were used to provide respondents with characteristics such as geographic distribution, project team experience, and respondents' awareness of BIM aspects and performance domains, providing an overview of trends and differences within the collected data. Correlation analysis helped identify relationships between BIM aspects and pinpointed those with the weakest correlations. The study also mainly investigates the implementation of ordinal regression in determining factors that significantly affect the improvement of results or variables that negatively affect the various performance domains. North Africa and the Gulf countries have demonstrated a higher level of BIM level while in Iraq and the Levant have been lower. This implies that these regions encounter substantial obstacles, including inadequate infrastructure or a lack of training. The research indicates that more complex projects are typically overseen by experienced teams and employ advanced BIM levels, particularly BIM Level 2, indicating the need for skilled teams to manage project challenges. The Friedman test found team collaboration to be the most important performance domain, emphasizing the necessity for clear responsibilities and a shared vision for project success. while measurement tracking domain was placed lowest, presumably because it was seen as a monitoring tool rather than a performance driver. In contrast, BIM training was prioritized highest, showing that respondents see it as essential for improving BIM adoption through practical learning. However, the BIM Analysis and Optimization Level (BAOL) of BIM was ranked as the lowest, likely as a result of the absence of standardized, interoperable systems for the management of complex projects within firms. Effective communication and collaboration are shown by favourable connections between BIM Information Delivery (BIDE) and Organisational Requirements (OIR) and BIM Collaboration (BCC) and Training (BTC). Analysis and optimisation have weak relationships in BIM, suggesting they are underutilised and might benefit from improved integration. Since these domains are closely related to the information management components of data delivery, efficient handling, and explicit requirements. This suggests that concerns with data and requirements management can greatly improve project success. It was also found that the BIM integration aspects, which include establishing budgeting systems and effective communication channels, have a significant impact on most domains of performance, as enhancing communication between stakeholders increases the likelihood of project success. BIM integration variables had a significant impact in particular areas of team management, project processes, measurement and planning tools, and uncertainty management. Furthermore, the technical aspects of BIM, which represent modeling and optimization capabilities, have a unique impact only on the project work performance domains. This finding indicates that although BIM techniques in modeling, conflict detection, and energy analysis are of significant value, their contribution to project success more broadly depends on the extent of their integration into management and communication processes. The study suggests exploring external factors that affect BIM adoption, understanding the negative impacts of BIM on certain performance domains, and identifying barriers to successful BIM implementation. In addition, there is a need to develop strategies and automated roadmaps tailored to specific regional needs because there are different levels of BIM adoption from one region to another and a uniform approach to BIM implementation may not be effective. Finally, integrating emerging technologies like Artificial Intelligence (AI) and the Internet of Things (IoT) with BIM could enhance its capabilities, leading to more efficient and data-rich project management.

6. Appendix

6.1. Questionnaire Content

Evaluating BIM's Impact on Project Performance in the AEC Industry of the MENA Region

Introduction to the Questionnaire

Dear Participant,

Thank you for participating in this survey. My name is Migsid, and I am a master's student in the Engineering Management Department at Istanbul Kültür University. This survey is part of my thesis research aimed at evaluating project performance domains and the impact of Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) industry in the Middle East and North Africa (MENA) region.

Purpose Statement: This survey gathers insights from AEC professionals to understand current practices, challenges, and the impact of BIM on project performance. The feedback will refine the final questionnaire for reliability and validity.

Estimated Time: The survey will take approximately 5-10 minutes to complete.

Benefits of Participation: Your responses will enhance your understanding of BIM implementation in the AEC industry. Findings will improve the final survey instrument for clarity and effectiveness.

Ethical Considerations: Your participation is voluntary, and you may withdraw at any time. All responses are confidential and used solely for academic purposes, with no personal identifiers collected. Data will be securely stored and accessible only to the research team.

Consent: By clicking "Agree" and completing the questionnaire, you provide electronic consent to participate in this study. Your contribution is invaluable and greatly appreciated.

Completion Instructions: Please answer all questions to the best of your ability. If you feel uncomfortable answering any question, please provide feedback and move to the next one.

Contact Information: For inquiries, please contact me at: 2100000707@stu.iku.edu.tr.

Consent:

- Agree
- Disagree

Thank you for agreeing to take part in this survey. Your insights are instrumental in understanding current practices, challenges, and the effects of BIM on project performance.

Section 1: Your Experience with BIM

1.1 Before taking this survey, have you ever heard of BIM (Building Information Modelling)?

- Yes
- No

1.2 What level of BIM is currently being implemented in your organization?

Note: Our approach is influenced by standards and guidelines set forth by the National Bureau of Standards, now known as the National Institute of Standards and Technology (NIST).

- Level 0 BIM - No collaboration, 2D CAD drafting only, output via paper or electronic prints.
- Level 1 BIM - Mixture of 3D CAD for concept work and 2D CAD for drafting, with data sharing from a Common Data Environment (CDE).
- Level 2 BIM - Collaborative working with project-specific information exchange, using common file formats like IFC or COBie.
- Level 3 BIM - Includes 'Open Data' standards, new contractual frameworks, and comprehensive collaboration.

Section 2: Respondent and Project Background Information

1. Type of Project:

   ■ Residential ■Commercial ■Infrastructure

2. Geographical Location:

   ■North Africa ■ GCC (Gulf Cooperation Council) ■ Levant (Syria, Lebanon, Palestine, Jordan) ■ Iraq ■ Türkiye

3. Experience of the Project Team:

   ■ Less than 3 years ■3-5 years ■ 5-10 years ■ 10-20 years ■ More than 20 years

4. Project Complexity:

   ■Very Low■ Low ■Moderate ■High ■Very High

5. Role of Respondent:

   ■Owner / Client ■Contractor ■Specialist Subcontractor ■Site Supervisor ■Quantity Surveyor

   ■Civil / Structural Engineer ■Architecture Engineer ■ MEP Engineer ■Project Manager

   ■Project Coordinator ■Planning Engineer

6. Type of Organization:

   ■Consulting Office ■Contracting Company ■Government Institution ■NGO Institution

Section 3: Performance Domains Assessment

Instructions: Please rate your agreement with the following statements based on your experience with the project. Use the scale:

1 = Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

2.1 Stakeholder Satisfaction

The level of stakeholder satisfaction was exceptional, reflecting a thorough process of identifying stakeholders, involving them in crucial decision-making and ensuring clear and consistent communication throughout the project.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.2 Team Collaboration

The project teams demonstrated high effectiveness by clearly defining roles and responsibilities, establishing a unified vision, and fostering a positive and collaborative team culture.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.3 Project Lifecycle Alignment

The project's development approach was impeccably aligned with its nature (Agile, Waterfall, or Hybrid) and deliverables (single, multiple, or periodic), ensuring an appropriate and consistent delivery cadence that matched project goals.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.4 Strategic Planning Efficiency

Strategic planning was highly efficient, adeptly managing changes, adapting schedules, accurately estimating finances, and automating budget management to ensure smooth project progression.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.5 Project Operations Effectiveness

Project operations were extremely effective, optimizing processes for continuous learning, synchronizing resources with schedules seamlessly, and meticulously evaluating contractors and bids.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.6 Project Delivery Excellence

The project excelled in identifying requirements and managing the business case, ensuring compliance with quality standards, and implementing effective change management strategies.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.7 Balanced KPIs and Comprehensive Metrics Tracking

The performance measurement approach was robust, utilizing balanced Key Performance Indicators (KPIs) and comprehensive metrics tracking to gauge success accurately.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

2.8 Risk and Complexity Management

The project managed risk and complexity with precision, employing systematic approaches to navigate and mitigate ambiguity and complexity effectively.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

Section 4: Specific BIM Aspects and Their Implementation

Instructions: Please rate your agreement with the following statements based on your experience in the project.

Use the scale 1 = Strongly disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

4.1 BIM Information Requirements Management (BIRM)

4.1.1 Organizational Information Requirements (OIR):

The information management met organizational needs and aligned with strategies.

Details: Organizational Information Requirements (OIR) represent the information needs of a company's different departments. It makes sure that accurate information is provided to the various business functions, enabling well-informed decision-making and effective asset management throughout their lifecycle.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.1.2 Asset Information Requirements (AIR):

The Asset Information Requirements (AIR) were clearly defined and effectively communicated, facilitating successful asset management and project outcomes.

Details: They include information derived from organizational policies, asset monitoring, and stakeholder needs.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.1.3 Project Information Requirements (PIR):

The PIR in our project is clearly defined, effectively communicated, and adequately utilized to support key decision points and project milestones.

Details: PIR identified the necessary information at key decision points, was derived partly from Organizational Information Requirements (OIR), and included relevant OIR, project business cases, strategic briefs, project stakeholders, and project tasks.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.1.4 Exchange Information Requirements (EIR):

The Exchange Information Requirements (EIR) were well integrated into our project.

Details: The EIR includes specifying the required information at each stage of the project, ensuring detailed contractual obligations, supporting interoperability between systems, and providing a basis for verifying that delivered information meets the requirements.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.2 BIM Information Delivery Efficiency (BIDE):

The overall efficiency of our recent project was high in terms of timeliness, completeness, accuracy, compliance, and the number of revisions required as specified in both the Master Information Delivery Plan (MIDP) and the Task Information Delivery Plan (TIDP).

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.3 BIM Analysis and Optimization Level (BAOL):

BIM Analysis was carried on to the full extend succesfully.

Example: Our project used full integration of BIM tools, extensive clash detection, and fully standardized energy analysis to enhance performance and resolve conflicts.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.4 BIM scheduling, Cost and Material Management (BSCMM):

The level of BIM Cost and Material Management was highly efficient.

Example: Our project used methods like Quantity Takeoff (QTO), scheduling information 4D, parametric cost estimating 5D, assembly-based estimating, and integration with cost databases.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.5 BIM Quality Control and Validation (BQCV):

The level of BIM Quality Control and Validation was highly compliant with standards.

Example: Our project adhered to naming conventions, file formats, and levels of detail as per EIR and BEP, validated through checklists and a CDE solution during data upload.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.6 BIM Collaboration and Communication (BCC):

The level of BIM Collaboration and Communication was fully integrated.

Example: "Our project used regular coordination meetings and BIMCloud to optimize BIM information exchange with enhanced data models and social interactions.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

4.7 BIM Training and Competence (BTC):

The level of BIM Training and Competence was high.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5

6.2. Normality Test Calculation:

Table 24: Normality test

Variable	Kolmogorov-Smirnov (Statistic)	Kolmogorov-Smirnov (df)	Kolmogorov-Smirnov (Sig.)	Shapiro-Wilk (Statistic)	Shapiro-Wilk (df)	Shapiro-Wilk (Sig.)
Stakeholder Satisfaction	0.271	131	0.000	0.862	131	0.000
Team Collaboration	0.350	131	0.000	0.763	131	0.000
Project Lifecycle Alignment	0.332	131	0.000	0.758	131	0.000
Strategic Planning Efficiency	0.282	131	0.000	0.841	131	0.000
Project Operations Effectiveness	0.289	131	0.000	0.835	131	0.000
Project Delivery Excellence	0.261	131	0.000	0.878	131	0.000
Metrics Tracking	0.255	131	0.000	0.842	131	0.000
OIR	0.277	131	0.000	0.844	131	0.000
AIR	0.345	131	0.000	0.808	131	0.000
PIR	0.306	131	0.000	0.844	131	0.000
EIR	0.259	131	0.000	0.886	131	0.000
BIDE	0.274	131	0.000	0.874	131	0.000
BAOL	0.247	131	0.000	0.851	131	0.000
BSCMM	0.302	131	0.000	0.804	131	0.000

BQCV	0.227	131	0.000	0.896	131	0.000
BCC	0.342	131	0.000	0.779	131	0.000
BTC	0.314	131	0.000	0.766	131	0.000

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