A Blockchain-based tool for improving the management of assets information models

Azzam Raslan

Thesis submitted to the University of Nottingham
for the degree of Doctor of Philosophy

April 2024

if you AIM, AIM at the stars .. So, if you miss, you land on the moon.

Abstract

Recently, businesses and government bodies in the Architecture, Engineering, and Construction (AEC) sector have faced a key challenge in the delivery of effective project outcomes. Asset Information Modelling (AIM) is aimed to serve the asset process once the project is handed over. Considering that Blockchain is a relatively new data management technology, that is intended to provide security within a decentralized culture, it could be the foundation for improving asset processes.

Currently, owners find it difficult to manage their assets throughout their lifecycle. The fact that Asset Information Models (AIMs) are mandatory as deliverables in Building Information Modelling (BIM) driven projects, then is a key requirement for the client to understand in detail those factors affecting assets operation.

Hence, the Kingdom of Saudi Arabia is the most significant market in the Middle East, the researcher investigated those factors where Blockchain and AIMs could impact on AM lifecycle. The lack of an integrated system and the use of new technology lead to fragmentation in the building process. There is an urgent need, therefore, for the adoption of new technology in the construction industry, to support building assets. With the aim of overcoming current limitations in construction and AM, by using Blockchain technology, with its novel way of managing – storing – and sharing data in various ways, it can be considered a new revolution amongst the most advanced construction applications. Therefore, this thesis aims to assemble a Blockchain-based tool that can improve the management of AIMs. The researcher used a hypothesis-based approach over a systematic literature review and a workshop (descriptive statistics) to understand the current challenges in Asset Management (AM) within the context of the Kingdom of Saudi Arabia (KSA).

On this ground, a workshop was run to understand the impact factor analysis affecting the operation of asset lifecycle by using Asset Information Modelling and Blockchain technology over a mixed method (Phase 1). Results have shown, amongst others such as poor communication, poor coordination, lack of a consistent approach in building construction, inconsistent language, lack of accurate data and data management, less value for investments, and unplanned decision-making.

In Phase 2, with the same group of experts, a survey was conducted using descriptive statistics to test the impact of project delivery on the efficiency of the operating asset information modeling and management. Results show relatively strong evidence of the impact of the operating AIMs in different AM lifecycle stages including potential consequences.

Since research and systematic literature review showed evidence of a lack of sharing, transferring, and protecting the information between stakeholders then Blockchain was introduced aiming to assess whether and how Blockchain could impact AIM throughout the lifecycle. On this ground, the researcher designed

and developed a Blockchain-based tool aiming to understand these interrelationships (using C++, HTML, Java, Python, and Javascript), and ensure ISO 19650 and ISO 55000 compliance.

To validate this Blockchain-based tool the research used an experiment within the King Abdulaziz University (KAAU) in the KSA (Phase 3). A group of 5 team members was invited to test whether and how Blockchain technology could be operated and whether changes are required during asset operations.

In the running of the workshop, hypotheses were developed (different AM stages) in which assets' stakeholders (owners, consultants, contractors, and suppliers) had the opportunity to upload, visualize, review, select, and decide the best product based on the asset information model during the tendering stage (smart contracts) of asset's operation.

Results show that factors affecting the operation of assets are the improvement of trust and improved stakeholder influences; availability of handover process products' accurate data; provision of details provided by manufacturers; increase in the speed of preparing holistic and integrated Asset Management Systems, improvement of collaboration between stakeholders, and returning faster clients' Return of Investment due to the prompt response when and as a problem occurred.

Understanding the factors affecting the AM lifecycle based on the utilization of AIMs and Blockchain will allow investors and their team members to work in a secure and collaborative environment that helps them pre-identify certain risks and become proactive, identify which digital asset data could add value to the owners (decision purposes) and innovate by elaborating and improving day-to-day business through an integrated procedure based on international standards.

Acknowledgements

I dedicate this research to the unwavering support of those who encouraged and stood by me throughout this journey. In particular, I extend my deepest gratitude to my family: Mr. Waddah Raslan, your presence fills my life with joy; Shrazad Shniah, I am blessed to call you my mother; my brother, sisters, wife, and daughter, your constant encouragement fuels my determination. Thank you for being my pillars of strength.

I extend my deepest gratitude to my supervisors, Professor Georgios Kapogiannis, Professor Dave Towey, Professor Ali Cheshmehzangi, and Professor Walid Tizani, whose unwavering support has been a guiding light throughout my journey. From the depths of my heart, I pray for blessings upon you all.

I am also grateful to my friends and colleagues, Engr Mohammed Hatersh and Professor Tariq Malatani, whose encouragement has meant the world to me. May you both achieve every success in your endeavors.

Special thanks are also due to the Saudi Council of Engineering (SCE), the King Abdul-Aziz University (KAAU), and Modern Cities Consultant Engineering (MCEC) for their invaluable support.

List of Publications

1. Raslan, A., Kapogiannis, G., Cheshmehzangi, A., Tizani, W., and Towey, D. (2020, July). Blockchain: Future Facilitator of Asset Information Modelling and Management? In 2020 IEEE 44th Annual Computers, Software, and Applications Conference (COMPSAC) (pp. 523-528). IEEE.

2. Raslan, A., Kapogiannis, G., Cheshmehzangi, A., Tizani, W., and Towey, D. (2020, July). A Framework for Assembling Asset Information Models (AIMs) through Permissioned Blockchain. In 2020 IEEE 44th Annual Computers, Software, and Applications Conference (COMPSAC) (pp. 529-534). IEEE.

3. Raslan, A., Cheshmehzangi, A., Towey, D., Tizani, W., and Kapogiannis, G. (2024). Impact factor analysis affecting the operation of asset lifecycle by using asset information modeling and blockchain technology. Construction Innovation.

4. A Blockchain-based tool for improving the management of assets information models (Submitted Rev 002)

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Chapter 1

Introduction

This introductory chapter provides an overview of the research topic, which investigated the integration of AIM and Blockchain technology within the AM lifecycle. The chapter begins by highlighting the persistent challenges faced by the global construction industry, particularly in the KSA, such as budget constraints, schedule adherence, and quality standards. It underscores the lack of established procurement procedures and the absence of contractual formats safeguarding clients' rights, leading to contractors' challenges in understanding client requirements throughout the AM lifecycle. It further discusses the fragmented nature of the construction industry, where disjointed operations AM and a lack of collaborative ethos hinder the establishment of enduring relationships among asset stakeholders. Moreover, this chapter also highlights the potential of Blockchain technology to address the fundamental need for enhanced asset data management and security within a decentralised cultural framework. It outlines the research rationale, which includes exploring the interrelationship between AIM and Blockchain, investigating the factors affecting the operation of the asset lifecycle, and designing a tool to create a decentralised application for stakeholders to store and manage AIM models. Additionally, the chapter presents the research questions, aim, scope, and objectives, emphasising the goal of enhancing the efficiency of the AM lifecycle.

1.1 Background

The global construction industry, which encompasses both public and private sectors, faces persistent challenges in AM, including budget constraints, adherence schedules, and the maintenance of expected quality standards [4]. Within the KSA, these challenges are exacerbated by a lack of established procurement procedures throughout the project lifecycle. This inadequacy stems from clients' inexperience in selecting appropriate procurement types and the absence of contractual formats safeguarding clients' rights [5]. Additionally, contractors often struggle with a lack of clarity regarding client requirements [6].

Consequently, the existing procurement framework in KSA remains in its infancy, primarily concentrating on the construction phase rather than incorporating operational considerations [7]. Given KSA's prominence as the leading construction market in the Middle East [8], the necessity for a robust procurement system, coupled with essential technical and contractual proficiencies, becomes paramount for successfully executing projects spanning various infrastructural domains such as buildings and roads [9]. Extensive literature highlights procurement as a significant impediment to technological adoption within the construction sector. Notably, Mohammed Al-Sheikh, an adviser to the crown prince, attributes substantial annual losses, estimated at USD 80 billion to 100 billion, to inefficient procurement practices within the Saudi government [10].

Additionally, a lack of collaborative ethos hampers the establishment of enduring relationships between suppliers and contractors [6]. Therefore, fostering a collaboration culture is imperative to enhance efficiency and quality across construction processes [11]. Reports by Latham [12] and Egan [13] underline the centrality of trust and collaboration between clients and contractors for project success, advocating for early problem identification and resolution through closer cooperation among stakeholders.

While procurement inefficiencies pervade the construction industry, exceptions exist, such as the Heathrow Airport terminal project in the UK [4]. Most studies advocate for the integration of procurement at each asset lifecycle stage to ensure optimal outcomes. The Chartered Institute of Building's research also shows that improving the procurement process throughout the project lifecycle is important for project success, with 87% of survey participants supporting this idea, especially during the AM phase [14]. Hence, the judicious selection of procurement systems emerges as a critical determinant of project efficacy, propelling researchers to examine various procurement models in recent years.

Despite strides, the prevailing construction business model remains fragmented, reflective of the industry's reliance on disparate communication modes among entities [15]. This fragmentation underscores the imperative for technological interventions to augment communication and collaboration during procurement processes, particularly in KSA, where projects encounter significant challenges during the handover stage [16]. Furthermore, throughout the various phases of the construction project lifecycle, a lack of accurate and valid project data pertaining to building assets exists [6]. This deficiency in building data integrity poses substantial obstacles to effective AM and decision-making processes. A fundamental approach for enhancing these processes may lie in adopting novel asset data management technologies designed to ensure security within a decentralised cultural framework.

BIM emerges as a promising paradigm. To optimise digital building management processes, stakeholders must enhance information exchange, adhering to standards such as ISO-19650 [2]. While conventional data exchange formats are limited to 2D drawings and Word documents, BIM's dynamic involvement facilitates broader access to data [2]. As a result, securing asset data access and visualisation is crucial for leveraging existing insights and discovering new areas, thereby increasing asset value over time. According to ISO-19650 [2], projects driven by BIM are required to submit both graphical and non-graphical project data, including the AIM, during the handover stage.

Furthermore, studies have shown that integrating AIM and BIM more closely can highlight the added value and ROI across various AM horizons [17]. AIM, encompassing the base and operational models, entails recording all activities throughout the project lifecycle, particularly during the operational phase [18]. However, integrating AIM and BIM presents challenges, including skill shortages and technological adeptness among stakeholders [19].

The research in this thesis addresses critical challenges within the Saudi construction industry, specifically the issue of managing building assets due to the absence of accurate and reliable project/asset data. This lack of quality data hinders effective AM and decision-making, leading to inefficiencies and potential setbacks in construction projects. To overcome these obstacles, the thesis proposes an innovative Blockchain-based tool designed to integrate with AIM, offering a solution tailored to the unique needs and challenges of the Saudi construction sector. The inefficiencies in the Saudi construction industry can be primarily attributed to the current work practices that separate architects from builders during the design phase.

However, this separation persists throughout the AM lifecycle. This separation poses significant challenges for effective communication between stakeholders, resulting in suboptimal project delivery [20]. Hence, there is a need to develop procurement processes that connect clients and contractors from start to finish of an asset's lifecycle [8] Several factors contribute to this focus: clients frequently face difficulties in choosing appropriate procurement methods, and there is a lack of contract templates that effectively protect client rights [5]. As a result, contractors frequently deal with understanding the client's brief [7].

Hence, as Raslan and Kapogiannis [8], have noted there is a requirement to close the gap between client and contractor throughout the AM lifecycle. In addition, a comprehensive literature review has revealed that the asset lifecycle is one of the primary obstacles hindering technology integration in the construction sector (details in Chapter 2). Despite the potential for new technologies to enhance construction performance and facilitate client participation at the early stages, the industry's reluctance to embrace collaborative practices has stymied their adoption [8], [19], and [21]. In light of the escalating demand within the construction industry and the paucity of existing technologies, there is an urgent need to revitalise strategies.

AIM is introduced to oversee, enhance, and incorporate different elements of the AM strategy [22]. AIM refers to the asset models that document actions throughout the project lifecycle and into the AM. AIM represents the as-built model that encapsulates the asset lifecycle [23]. BIM is a strategy that serves the construction industry by employing processes to enhance planning and design. As a principle, BIM has the potential to empower teams to enhance their knowledge and share relevant information effectively.

Presently, BIM is employed in developed construction industries such as in the United Kingdom, China, Hong Kong, Norway, Denmark, and Australia. BIM, as a process, can revolutionise the entire work environment by reducing resource waste, costs, and materials while providing a more accurate approach to project execution [24]. The design stage of a project is crucial. It significantly impacts the asset's lifecycle. This phase requires attention to enhance quality. Detecting clashes before the construction stage is essential. This early detection also benefits the AM lifecycle stage. Therefore, BIM visualisation tools, along with the provision of real-time data, are essential for enabling comprehensive management and collaboration at every stage of the project lifecycle, including the AM phase [25].

Building on this, the adoption of Blockchain technology complements the AEC (Architecture, Engineering, and Construction) industry's shift from Computer-Aided Design (CAD) to BIM. This transition aims to enable smooth data recording, system updates, and improved security [26] enhancing the industry's operational efficiency and integrity throughout the AM lifecycle. Blockchain technology is made up of two key elements: the ledger, which acts as a comprehensive record, and the individual units recorded on this ledger [27].

This technology functions through a network of nodes (computers connected to the Blockchain network), with each node required to maintain a copy of all transaction blocks (Each node stores transactions in blocks and to ensure the accuracy of the entire transaction history, every node must keep a copy of these blocks.) This redundancy is crucial for verifying the entirety of transactions across the system [28]. Each block is linked to the preceding one by a unique code, known as a hash from the previous blocks (hence having Blockchain) to safeguard the system. This method not only facilitates the systematic gathering of transaction data but also ensures the integrity of this data, protecting it from altering [29]. Similarly, both BIM and Blockchain technology encounter a common obstacle: the lack of established standards and clear guidelines for their implementation [30]. Blockchain technology finds applications across various domains, including financial services, government, healthcare, money, and smart contracts [31]. This gap in standardised practices is anticipated to significantly affect the process of recognising and meeting client demands and specifications. The absence of clear standards complicates the application of these technologies, potentially hindering their effectiveness in satisfying specific client requirements.

Blockchain technology has been applied across various domains, including financial services, government, healthcare, money, and smart contracts [30]. Nevertheless, this thesis focused on smart contracts to examine their feasibility throughout the asset lifecycle. A smart contract can be defined as a computerised transaction protocol that executes the terms of a contract [32]. The general objective is to satisfy common contractual conditions, such as payment terms, liens, confidentiality, and enforcement [28]. This method serves as a way to decrease both intentional and unintentional errors and reduce third-party involvement, thereby minimising the risk to AM. In addition, its economic objectives encompass reducing fraud-related losses, costs associated with arbitration and enforcement, and other transaction expenses [2].

Therefore, a smart contract can be viewed as an independent digital mechanism that activates automatically once certain predetermined conditions are met, all enabled by Blockchain technology [33]. This enables the seamless and automated enactment of agreements when predetermined requirements are met within the AM lifecycle. Such a setup could foster a cooperative atmosphere where clients and contractors can interact with and manage asset data, thereby cultivating trust through collaboration [11].

However, integrating AIM-BIM across the entire asset lifecycle presents obstacles. To address these challenges, this research proposes a Blockchain-based environment designed to meet the critical needs of clients in the efficient and streamlined management of their assets. Therefore, in summarising the points discussed above, five key observations are identified: Fragmentation emerges as a central issue within the construction process, occurring at both project and industry levels. This fragmentation in multi-activity projects with diverse contractors and subcontractors leads to a lack of cohesive data exchange among assets' stakeholders. Indeed, the construction industry is often cited as one of the most fragmented sectors [34]. Traditionally, asset data accumulation reaches its peak during the construction stage but experiences a sharp decline during the handover phase, a situation worsened by the reliance on manual paperwork submissions [35]. This lack of structured information storage procedures results in owners facing substantial data backup and protection hurdles. As a result, owners frequently face extra expenses to regain asset data in the AM phase, paying again for the detailed as-built information and data that should have been accurately captured and transferred during the handover phase.

Technicallay, there are multiple challenges related to the transformation of asset data that demand attention. These include, for example, the handling of large files like BIM and AIM models, Organizational Information Requirements (OIR) files, etc., the absence of adequate tools for model revision management, the need for manual intervention in data exchanges, complications arising from software bugs and instability, and the imperative to review and modify architectural elements, costing details, and construction resources resources [35].

To enhance the suggestion from previous studies, establishing precise criteria for the standards of asset information and the methods by which it is delivered is essential [2]. Notably, the costs linked to operations and maintenance account for a significant portion of the overall lifecycle expenses of a building or facility [34]. This fact highlights the integral role of effective Facility Management (FM) in enhancing the AM lifecycle. FM supports operational efficiency and directly contributes to informed decision-making throughout the stages of AM, ensuring a seamless connection between daily operations and long-term asset strategy as per AM ISO-55000 [36].

Blockchain technology could offer a paradigm shift in asset data management, characterised by decentralisation and enhanced transparency. Unlike traditional centralised databases, Blockchain eliminates the need for intermediaries, providing participants with direct access to the entire database and transaction history. This decentralisation fosters trust among participants, as asset data is not controlled solely by a single entity[32] and [37]. However, Blockchain's potential role in fostering cooperation within the KSA construction context remains under-explored. Hence, these essential insights address the fragmentation problems and obstacles in managing asset data within the AEC industry. They range from pinpointing the technical difficulties faced to offering feasible solutions and cutting-edge technologies like Blockchain that promise to address these concerns. Notably, the emphasis is on the integration of AIM and BIM via Blockchain technology as a strategy for improving coherence and efficiency throughout the AM lifecycle. This underscores the significant impact of refining AM practices and fostering the development of comprehensive asset information standards. Consequently, to explore these themes further in this Ph.D. research, the subsequent section will introduce research questions centered on these critical areas.

1.2 Research Questions

Based on the discussion and insights highlighted in the preceding text, the following research questions are proposed to guide the exploration and analysis of this PhD research:

1. **How does Blockchain technology facilitate the integration of AIM within the AM lifecycle, and what are its implications for AM?** This question seeks to explore the fundamental concepts of AIM and Blockchain technology, examining the role of Blockchain in enhancing AIM's application and effectiveness throughout the asset lifecycle.

2. **How can a Blockchain-based tool integrated with AIM be designed, developed, and validated to improve the AM lifecycle?** The focus here is on the practical application of Blockchain technology with AIM through designing, developing, and validating a tool specifically aimed at improving the AM lifecycle. This question also considers the expected impacts and improvements from deploying such a tool in real-world settings.

3. **What added value does Blockchain technology with AIM bring to the AM lifecycle, and how does it contribute to operational**

efficiency? This question aims to investigate the specific benefits and enhancements that Blockchain technology introduces to the AM lifecycle, focusing on improvements in operational efficiencies, data integrity, and stakeholder collaboration throughout the AM lifecycle.

These questions have been designed to facilitate a comprehensive evaluation of how Blockchain technology can play a transformative role in enhancing Additive Manufacturing (AM) and Artificial Intelligence in Manufacturing (AIM) within the construction industry. This aligns with our research goals to explore, examine, and drive innovation in this burgeoning field. By focusing on the facilitation of AIM and identifying operational factors influenced by Blockchain, this research aims to contribute significantly to the optimisation and enhancement of AM practices. The integration of Blockchain with AIM represents a pioneering approach that could lead to groundbreaking improvements in the way assets are managed across their lifecycle, offering insights into a future where digital and decentralised technologies drive the construction industry forward.

1.3 Aim and Objectives

Based on the research question in section 1.4, this research aims to explore and validate the transformative potential of Blockchain technology in enhancing AIM and AM practices within the AM lifecycle. Specifically, it seeks to develop a Blockchain-based tool that facilitates a decentralised approach to managing and optimising the transactions and interactions between digital models and various stakeholders across the asset lifecycle. This **aim** is driven by the objective of adding value for all stakeholders involved, improving the AM process, and contributing to the body of knowledge on integrating Blockchain technology with AIM to address the persistent challenges in AM. Hence, the **objectives** are:

1. **Exploration of Blockchain and AIM Synergy:**to examine how Blockchain technology enhances AIM integration within the AM lifecycle and to understand its broader implications for the field of AM.

2. **Development and Validation of an AIM-Blockchain Tool**: to design, develop, and systematically validate a Blockchain-based tool that is integrated with AIM, aimed at streamlining the AM lifecycle, and to evaluate the expected outcomes of its real-world implementation.

3. **Assessment of Blockchain's Added Value with AIM**: to investigate the additional benefits Blockchain technology brings when combined with AIM in the AM lifecycle, mainly how it boosts operational efficiency, improves data safety, and fosters stakeholder collaboration.

Hence, this research leverages the empowering potential of Blockchain technology to revolutionise AM practices, particularly through AIM. By proposing a Blockchain-based application, the study aims to enable asset stakeholders to efficiently upload, manage, and visualise asset data throughout the building's lifecycle, thereby enhancing decision-making and optimising transactions between digital models and stakeholders. The research objectives are aligned with exploring the fundamental concepts of AIM and Blockchain, investigating the added value these technologies bring to the AM lifecycle, and designing a practical Blockchain-based tool to improve this lifecycle. This approach not only promises to elucidate the critical relationships between various informational requirements within AIM but also aims to contribute to the growing body of knowledge on digital solutions in AM. Through a holistic exploration and practical application, the study seeks to address the nuanced challenges of the AM lifecycle, offering a significant advancement in digital AM practices.

1.4 Structure of the Thesis

Chapter 1: Introduction to the Research Domain: this introductory chapter laid the groundwork for the study by detailing the background and the existing hurdles within the AM field. It emphasised the transition from BIM to AIM and presented Blockchain technology as an innovative solution to these hurdles. The chapter outlined the research questions, aims, and objectives, thus providing a framework for the research. It supported the integration of AIM and Blockchain technology as a strategy to address issues concerning data precision, security, and improving cooperative efforts among AM stakeholders. Furthermore, the introduction provided an outline of the thesis structure, preparing readers for a thorough exploration of literature, methodologies, results, and the confirmation of impact factors in the subsequent chapters.

Chapter 2: Literature Review on the Evolution from BIM to AIM and the Role of Blockchain: this chapter delves into the literature on the transition from BIM to AIM and the critical role of Blockchain technology. It reviews international standards like ISO-19650, explores the challenges in asset information management, and examines the potential for Blockchain to transform these practices. The literature review establishes the study's theoretical base, emphasising the technologies employed, testing methods, and principal results from merging AIM and Blockchain.

Chapter 3: Research Methodology: This chapter details the research methodology, describing how the study was designed to explore the integration of AIM and Blockchain. It explains the selection of case studies, data collection methods, research ethics, limitations, and analytical techniques employed to assess the impact of Blockchain-based AIM systems on AM practices. This methodology ensures a rigorous approach to achieving the study's aims and objectives.

Chapter 4: IT Prototype: this chapter presents an in-depth analysis of integrating AIM and Blockchain technology. It discusses the design and functionality of a Blockchain-based AIM system and its potential to enhance data security, accuracy, and stakeholder cooperation in AM. The integration addresses identified challenges, offering insights into the system's theoretical and practical benefits.

Chapter 5: Experiment: this chapter focuses on validating the impact factors crucial to the success of the Blockchain-based AIM system. Through empirical research, it assesses how the integrated system can improve operational efficiency, reduce costs, and support better decision-making in AM. This validation underscores the transformative potential of combining Blockchain with AIM and BIM.

Chapter 6: The Impact of Research: this chapter provides a comprehensive analysis and interpretation of the research results obtained in this research. This chapter aims to contextualise the findings within the broader framework of AIM, BIM, and Blockchain technology's impact on the asset lifecycle. By examining the data concerning the research objectives and questions, the chapter highlights the key insights regarding the facilitation of AIM through Blockchain, the added value Blockchain technology offers to the AM lifecycle, and the ability of a Blockchain-based tool to enhance AM practices. The discussion integrates theoretical perspectives with practical implications, evaluating how the findings align with existing literature and what they signify for future research and industry practice. Through this exploration, the chapter provides an understanding of the research's contributions to the field and its relevance to stakeholders in the AM sector.

Chapter 7: Conclusion: the conclusion summarises the key findings, emphasising the innovative contribution of integrating Blockchain technology with AIM to the field of AM. It highlights the study's implications for future research and the practical application of digital technologies in enhancing operational excellence across asset lifecycles.

1.5 Summary

This chapter has addressed the significant challenges encountered in AM within the KSA construction sector, underlining the need for enhanced asset data management and communication. It highlighted the lack of standardised data documentation and the dominance of informal information sharing as primary concerns. The research scope was defined by presenting the problem statement, research questions, aims, and objectives. The fragmentation in the AM lifecycle was acknowledged as a significant obstacle to efficient data exchange and collaboration, recommending the integration of Blockchain technology with AIM and BIM as an innovative solution. The necessity of implementing a Blockchain-based environment to secure AM data, ensure transparency, and maintain integrity was highlighted as critical for advancing toward more effective AM practices. Lastly, a preview of the thesis structure was provided, preparing the groundwork for a detailed examination of how a Blockchain-based tool could surmount these identified challenges.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a comprehensive overview of the background of the research aim, beginning with an introduction that contextualises subsequent analyses. Section 2.1 explores the chapter introduction, tracing the evolution from BIM to AIM throughout the asset lifecycle. Following this, Section 2.2 explores the research overview, laying the groundwork for understanding subsequent sections based on International Standard ISO-19650 [2]. This section is essential for establishing a foundational understanding of information and process management across the asset lifecycle. Section 2.3 Blockchain technology and smart contracts. Section 2.4 explores the discussion, offering insights into the practical application of theories and technologies discussed earlier within the context of the KSA. The examination of Blockchain Technology in Section 2.5 provides a summary of this innovative technology, setting the stage for its relevance to BIM/AIM and Blockchain.

2.2 Research Overview

Chapter 2 is strategically structured to progress logically from general concepts to specific applications and interrelations among asset lifecycle management, AIM, BIM, and Blockchain within the context of the KSA. The AEC industry, which represents a significant segment of the global economy, is characterised by fragmentation in its business model, primarily due to varied communication modes across different companies [15]. This fragmentation underscores the necessity for integrative processes like BIM, which has demonstrated its primary benefits during the asset's operational phase [16]. This integration offers a more organized approach to AM, encompassing efficient operation, maintenance, utilization, and disposal. AIM serves as a foundational and operational model capturing all activities across the project lifecycle, particularly during the operational phase [17]. However, integrating AIM and BIM presents challenges such as skill gaps and a lack of technological understanding among project stakeholders [2]. Additionally, the AM process itself demands improvement, particularly in capital and operational expenditure identification, resource management, systems engineering, technical standards, and maintenance delivery, aligned with ISO-19650 standards for information exchange among stakeholders [18].

The emergence of BIM has transformed this process, enabling dynamic access to project data, which underscores the importance of secure and properly distributed data among stakeholders [19]. Traditionally, information exchange during the project lifecycle has relied on 2D drawings, word documents, and spreadsheets [20] The emergence of BIM has transformed this process, enabling dynamic access to project data, which underscores the importance of secure and properly distributed data among stakeholders [30]. Blockchain technology, introduced in 2008 and operationalized in 2009 with the launch of Bitcoin, presents a promising solution to the challenges of secure data access and visualization, due to its inherent security features [31].

While Blockchain technology is being applied in various sectors, its potential for enhancing the security and accessibility of data through integration with AIM and BIM technologies is an area of ongoing research. This is particularly relevant in areas like the KSA, where challenges in data and information management remain [31] and [38].

In addition, there are notable inconsistencies in the transfer of information from project handover to AM, highlighting the crucial role of innovative approaches like Blockchain in refining AIM and BIM processes [22]. Moreover, the AEC industry in KSA is on the cusp of a significant transformation, with the integration of AIM, BIM, and Blockchain technologies promising to bridge current gaps in AM processes and lay the groundwork for a more efficient, secure, and technologically sophisticated industry framework. However, it's worth noting that the KSA has recently announced substantial investments in digital transformation, amounting to 35 billion SAR approximately 950 million USD [39], signaling a strong commitment to advancing technological integration and innovation.

Additionally, Table 2.1 illustrates the definition of each feature selected related to use in the construction sector, providing further clarity on the discussed concepts.

Table 2.1: Definition of matrix keywords.

Features	**Definition**
Collaboration	Stakeholders to act together for successful goal
Improve quality	Achieve the level of performance in each activity
Data security	Prohibit unauthorised access to data
Innovation	Improvement in services, products, and processes
Trust	Relationship among stakeholders
Share information	Information required to fulfill the needs
Confidentiality	Owner's privacy
Solve problems	Discover problems before they occur
Immutable	Unchangeable object
Accuracy of data	Correct data to be stored
Materialise	Realised outcomes
Cryptography	Protect owner's information

A considerable volume of research has thoroughly explored the characteristics and integration of AIM and BIM [11], [40], [41], [42], [43], [16], [44], [45], [46],

[15], [47], [48], [19], [49], [50]. While Blockchain technology's growth and its features, applications, and significance across various sectors, including AM, have been well-documented [33], [51], [31], [52], [53], [28], [54], [55], [56], [27], [57], [58], [59], [60], [38], [61]. research on leveraging Blockchain to enhance AM, especially in the AIM context, remains limited.

In the KSA, the procurement process among stakeholders throughout the asset lifecycle is notably deficient [5]. This deficiency is primarily attributed to clients' inexperience in selecting appropriate procurement types and the absence of contract formats that safeguard client rights. Furthermore, contractors often lack a clear understanding of the client's brief, exacerbating the situation [6]. Currently, the procurement system in KSA is still evolving [7], with a predominant focus on the construction phase rather than on operational sustainability. Given that KSA hosts the most significant construction market in the Middle East [39], featuring mega projects across buildings, roads, and other infrastructures, there is a critical need for an effective procurement system alongside robust technical and contractual competencies [9]. However, the integration of technology into construction processes faces challenges such as unclear agreements, insufficient funding, vague policies, time constraints, a shortage of skilled personnel, organisational culture, language barriers, and procurement challenges [8]. Procurement is a principal obstacle to technological adoption within the construction sector, as evidenced by the inefficiency highlighted by Mr. Mohammed Al-Sheikh, an adviser to the crown prince, attributing the Saudi government's annual wastage of USD 80 billion to 100 billion [10].

Linking this context to AIM, BIM, and Blockchain technology, it becomes evident that these technologies could play a transformative role in addressing the identified challenges. AIM and BIM can enhance the clarity and efficiency of project planning and execution, offering detailed visualisation and management tools that support better decision-making and collaboration among stakeholders.

When integrated with Blockchain technology, these models can further secure the procurement process, ensuring transparency, traceability, and accountability in contractual obligations and transactions.

This integration could mitigate many of the current challenges faced in the KSA construction industry, including those related to procurement, by fostering a more collaborative, efficient, and trustworthy AM environment. Therefore, exploring and adopting these technologies could be a significant step towards overcoming the systemic inefficiencies, and could enhance the success rate of construction projects in KSA.

2.2.1 The Pre and Post BIM Execution Plan: Navigating the Journey to AIM

The pre-contract BIM execution plan stands as a pivotal document in the hands of contractors, serving to outline their working methodology, as well as the capacity and capability of their company and supply chain to fulfil client requirements [62]. This comprehensive plan encompasses a wide array of essential project details, ranging from project information to client-specific requirements such as planning work, data segregation, coordination strategies, clash detection mechanisms, collaboration processes, common data environment (CDE) settings, health and safety protocols, and a detailed project implementation strategy. Additionally, it outlines the project's objectives, key milestones, and the strategy for delivering the project information model.

The adoption of a unified platform fosters a collaborative work environment for construction and design teams, centralising construction processes to mitigate risks and minimise the need for rework [19]. By implementing a BIM execution plan, project outcomes are significantly enhanced, streamlining decision-making processes, and expediting project completion [44] This strategic approach not only ensures a higher level of precision and efficiency in project execution but also aligns with the evolving demands of the construction industry for more integrated and collaborative project management practices [30]. Following contract signing, the post-contract BIM execution plan takes shape as a comprehensive document crafted by the contractor [63]. This document specifies the mutually agreed responsibilities, protocols for exchange, timelines for delivery, policies on reuse, and strategies for project handover. Additionally, it includes a comprehensive list of all activities outlined in the EIR.

Figure 2.1 visually represents the requirements of a construction project, providing a clear and structured overview of these essential components as per ISO-19650 [64]. This ensures a mutual understanding and alignment of expectations between the contractor and the client, facilitating a smoother project flow and enhancing the efficiency and effectiveness of the construction process. The con-

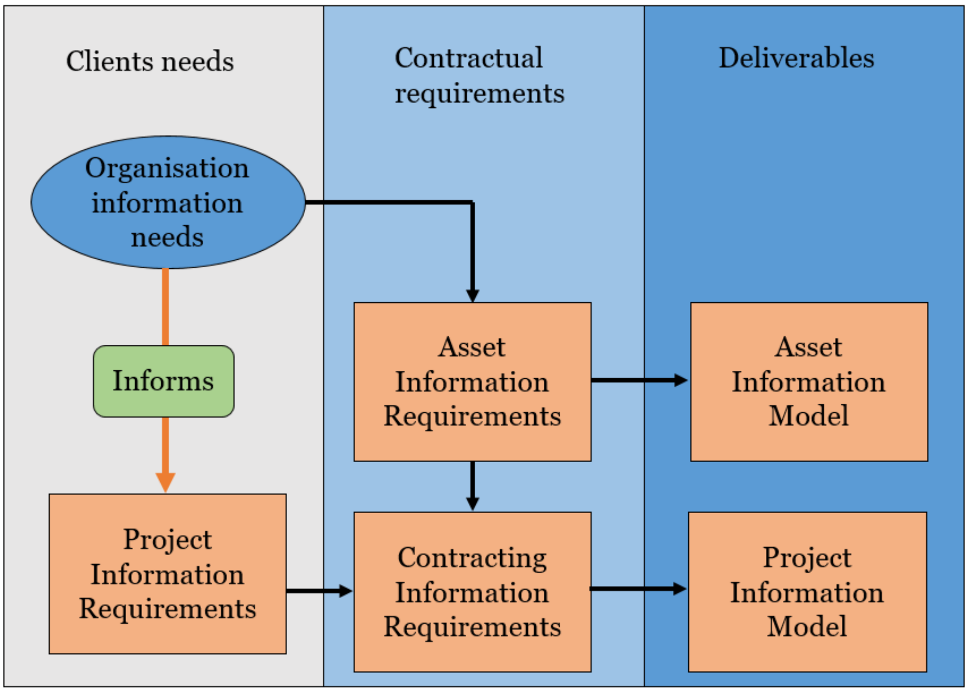

Figure 2.1: *Hierarchy of Information Requirements (Source: Adopted from ISO-19650 [2]).*

tractual landscape in construction serves to formalise the obligations and conditions agreed upon by the involved parties. Despite the complexity inherent in contracts [65], they are crucial in delineating roles, activities, timelines, costs, payment terms, and default remedies [66]. Whether modifying, constructing, renovating, repairing, or demolishing an asset, construction contracts aim for completion within agreed standards, timeframes, and budgets. The validation of these contracts through all parties' signatures underscores the critical need for comprehensive awareness of the details, conditions, and terms [67]. The distinction between non-standard and standard contract formats [68], introduces a layer of customisation and universality, respectively, catering to specific client-contractor needs or providing a globally recognised framework for construction projects. The evolution of standard contracts to address potential risks and issues signifies an industry-wide effort to minimise claims and disputes [69], guiding contractors in selecting appropriate contracts and highlighting potential risks from the outset.The existing hesitation among Saudi construction industry players to adopt varied contract formats, even with plans for future changes, underscores a wider issue in managing data and information throughout the asset lifecycle [8].

The importance of realistic, measurable EIR becomes apparent in this context, emphasising the need for a structured, legally sound, and technologically integrated approach to project management and execution [63]. This integrated perspective not only facilitates a more efficient and dispute-minimised construction process but also paves the way for leveraging BIM and related technologies to support the entire asset lifecycle, from planning through to operation and maintenance [2]. Linking these considerations to the development of AIM deliverables as per ISO-19650 [64], it becomes clear that the structured approach to BIM execution plans and contractual agreements is instrumental in laying the groundwork for effective AM and lifecycle management.

ISO-19650 [64], provides a framework for managing information over the whole lifecycle of a built asset, emphasising the importance of clear information requirements, structured data, and collaborative working environments. The integration of BIM execution plans with ISO-19650 deliverables facilitates a seamless transition into AM, ensuring that the data and information generated during the construction phase are accurately captured, stored, and utilised throughout the asset's lifecycle. This approach not only supports the operational phase of the asset but also enhances the overall AM strategy by providing a comprehensive, accurate, and accessible digital representation of the asset. Therefore, the thorough planning and execution detailed in the BIM execution plans, coupled with the contractual clarity and adherence to ISO-19650 [2] standards, are pivotal in realising the full potential of AIM in the context of lifecycle management.

2.2.2 BIM and ISO-19650

According to ISO-19650 standards, BIM is indicated as a transformative process with significant benefits for the construction industry. However, its application to projects presents stakeholders, including clients, consultants, and contractors, with challenges such as unskilled staff and poor performance [70]. These challenges underscore the critical importance of focusing on the design stage to enhance work quality and identify potential conflicts before proceeding to the construction phase. The design stage, therefore, emerges as a pivotal point affecting the project's lifecycle in numerous ways, necessitating the involvement of an accurate and skilled team. Inefficiencies highlighted by the Construction Owners Association of America reveal that over 63% of workforce time is wasted due to factors like waiting for material deliveries and unnecessary breaks, with labor costs constituting up to 40% of the total project budget [71]. This inefficiency underlines the need for improved project performance measurement and management, which serves as a significant Key Performance Indicator (KPI) for all stakeholders.

Furthermore, the shortage of skilled tradespeople, as highlighted by the Associated General Contractors of America, exacerbates the complexity of projects, increasing risks to progress, safety, and outcomes [72]. This challenge directly impacts AM by complicating the maintenance, upgrading, and efficient operation of assets, necessitating innovative solutions to mitigate these risks and ensure the longevity and reliability of assets throughout their lifecycle [71].

The industry's heavy reliance on raw materials also contributes to sustainability concerns and environmental degradation, with construction accounting for 25%-45% of global carbon emissions. Digital technology, particularly BIM, offers a promising pathway to success in addressing these challenges by reducing waste and increasing productivity. However, the industry's reputation for projects going over budget and schedule often stems from poor planning and insufficient communication among stakeholders. BIM proves instrumental in enhancing project performance, especially during the planning stage, by streamlining processes and improving coordination among information, people, and materials.

Despite the potential benefits, the widespread adoption of BIM faces obstacles, including a lack of information communication competence, and technical knowledge. BIM models hold the capacity to estimate the real value of projects, allowing for more accurate data gathering and error reduction during the planning stage. BIM significantly improves the construction industry's efficiency by facilitating dynamic information sharing. This technology enhances the precision of cost estimations and material quantifications, tackling a major industry hurdle: accurate cost forecasting, especially vital when transitioning AM to support facilities management.

BIM's utility now spans further, aiding in collaboration and clash detection (identifying clashes such as between digital objects like walls with beams, cables with pipes, etc.), as well as coordination concerning spatial location. It also acts as a 4D (time) and 5D (cost) modeling tool, providing valuable insights for time scheduling and financial planning. The role of the BIM manager is pivotal in facilitating this change, balancing cultural and technical factors. However, BIM's application has traditionally been limited to preplanning, design, construction, and management phases, with less focus on operations or maintenance processes. Table 2.2 illustrates the outlines the different dimensions of BIM models, each adding a layer of information or functionality to the preceding model: In the context of the Saudi construction industry, a notable gap exists in integrating AM within the procurement process. The adoption of AIM promises to bridge this gap by providing stakeholders access to comprehensive project data. Furthermore, the integration of Blockchain technology offers a robust solution for securely storing data in blocks, bolstering the roles of asset and facility managers in overseeing maintenance and operational processes [20].

However, understanding the delays in Saudi Construction Projects based on the literature review Table 2.3 highlights the potential challenges these projects face, indicating areas where improvements are necessary to enhance project efficiency and timeliness. Based on the above list alongside the adoption of ISO-19650, the Information Management International Standard for the Construction Sector within the KSA introduces a transformative approach to AIM and BIM. This standard directly addresses prevalent challenges such as contractor expertise gaps, poor project management skills, and ineffective planning and communication [85]. By standardising processes for information management across the asset lifecycle, ISO-19650 enhances the qualifications of technical staff, improves planning, scheduling, and cost estimation, and facilitates more effective collaboration and data sharing through a CDE [30].

Consequently, this leads to more accurate budgeting, timely project delivery, and the mitigation of cash flow issues, ensuring that even the lowest bidder contractors can deliver high-performance outcomes. Ultimately, the standard bolsters the efficiency, quality, and sustainability of construction projects, providing sig-

Table 2.2: Characterises of BIM model

BIM Model	BIM Features
2D Models	These are CAD (Computer-Aided Design) model applications that represent the project in two dimensions. They are the most basic form of BIM, focusing primarily on floor plans and elevations without depth or volume, and useful for initial design layouts and planning.
3D Models	These models add a third dimension to the 2D representations, offering a digital representation of the physical and functional characteristics of a place. This includes design details, tools, parameters, and object orientations, providing a comprehensive view of the project's architectural, structural, and MEP (Mechanical, Electrical, and Plumbing) components.
4D Models	The fourth dimension introduces time to the 3D model, transforming it into a tool for construction execution, schedule planning, and control. This dimension allows project managers to simulate construction processes over time, optimizing workflows and identifying potential scheduling conflicts.
5D Models	The fifth dimension incorporates cost estimation into the model, linking materials and labor to their associated costs directly within the BIM environment. This enables real-time budget tracking and cost control throughout the construction phase, facilitating more accurate financial planning and management.
6D Models	At this stage, sustainability becomes the focus. The 6D model is used during the operation phase of the building's life cycle, emphasizing the sustainability and environmental impact of the building. This dimension includes information necessary for maintaining energy efficiency, resource conservation, and overall sustainability performance metrics.
7D Models	The seventh dimension represents the entire asset lifecycle management, focusing on operation and maintenance execution. This extends the model's utility beyond construction to facilitate ongoing facilities management, including maintenance scheduling, asset inventories, and life-cycle costing. It's a comprehensive approach that ensures the efficient operation and management of the building post-construction.

Table 2.3: Summary of delays in Saudi construction projects

Authors	**Period**	**% of delay**	**Projects owners**	**Causes**
Al-Jarallah [73]	1983	70%	Ministry of Hosing	• Contractors lack of expertise. • Poor qualification. • Poor skills. • Inexperienced technical staff. • Poor planning. • Poor projects management skills • Poor scheduling. • Poor communication. • Poor cost estimation. • Cash flow problems faced clients and contractors. • Low performance of lowest bidder contractor in tendering system. • Delay in subcontractor's work . • Shortage of qualified engineers.
Al-Sultan, [74]	1989	70 %	Public projects	
Al-Sultan [75]	1996	61 %	Public projects	
Al-Ghafly [76]	2004	60%	Public projects	
Bubshait and Cunningham [77]	1998	70 %	Public projects	
Assaf and Al-Hejji [78]	2006	97 %	Public projects	
Albogamy et al., [79]	2012	60 %	Both sectors	
Elawi et al., [80]	2016	150 %	Public projects	
Mahamid [81]	2017	70 %	Private sectors	
Alhajri et al., [82]	2018	60 %	Public projects	
Alsuliman and Jawad [83]	2019	70 %	Public projects	
Gopang et al., [84]	2020	65 %	Public projects	

nificant added value to AIM and BIM practices in KSA and fostering a culture of excellence and innovation in the construction industry. This standard emphasizes the importance of a structured digital information model, where BIM's capabilities become important [19]. By adhering to ISO-19650, stakeholders can ensure that the information exchange is efficient, accurate, and effective, supporting the entire asset lifecycle from initial planning through to operation and maintenance.

The integration of BIM and AIM within the ISO-19650 framework ensures that all project and asset information is managed in a coherent and standardized manner. This not only facilitates improved project delivery and AM but also aligns with the principles of sustainability and efficiency. The use of Blockchain technology further enhances this integration by providing a secure and immutable record of all transactions and data exchanges, thereby ensuring the integrity and reliability of the asset information throughout its lifecycle. Furthermore, as per ISO-19650 [2], it is crucial to initially define the EIR strategy. This strategy leads to an Invitation to Tender (IT), Tender Responses (Pre-BEP), and subsequent appointment to deliver (Post-BEP) through mobilization, collaborative production, and ultimately, the delivery of the Project Information Model (PIM) to conclude and transfer the project. These stages generate a comprehensive AIM encompassing documentation, non-graphical, and graphical models, as depicted in Figure 2.2.

This structured approach ensures that all stakeholders are aligned and working towards the same objectives, enhancing project efficiency and success. Moreover, the primary challenges to authentic digital transformation in construction originate from the procurement process, affecting the entire asset and project lifecycle, as noted in [86]. The procurement process begins by compiling and defining the Exchange Information Requirements, essential for successful procurement and necessary for integration with smart contract requirements by converting files to a machine-readable format from formats like xls, pdf, doc, and dwg. Furthermore,

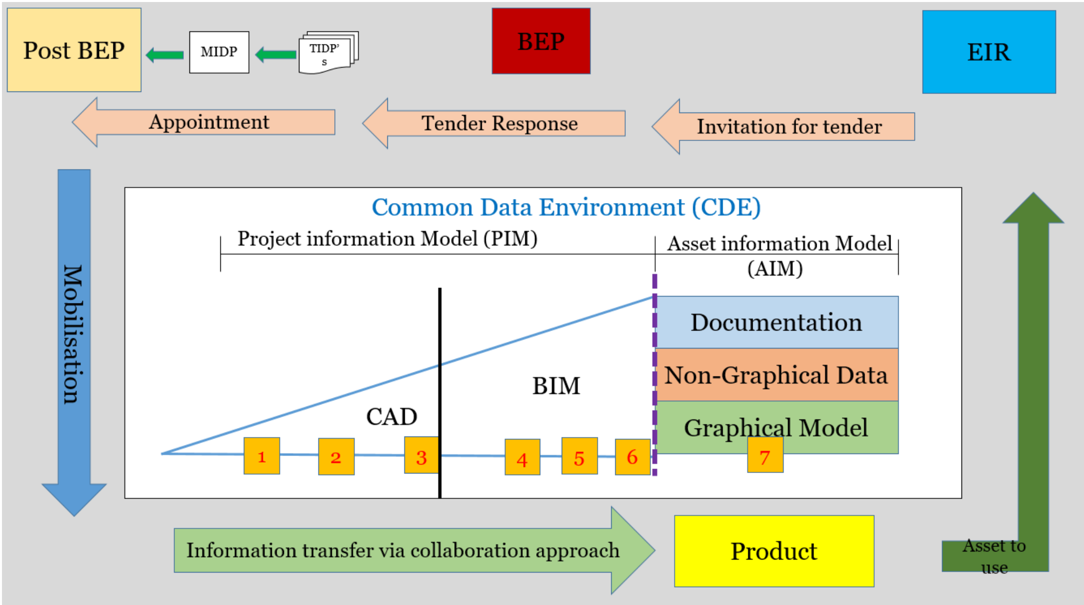

Figure 2.2: *Information Project Cycle (Source: Adopted from ISO-19650).*

[87] suggests a framework for the automated verification of supply chain deliverable documentation and data against the Asset Information Requirements (AIR), while [88] defines information requirements as essential documented evidence for process consistency. This information must align with the BIM Execution Plan (BEP), not typically in a machine-readable format, yet verifiable against the Master Information Delivery Plan (MIDP) through smart contracts. Ashworth [89], compares the process to completing a jigsaw puzzle, emphasising the importance of possessing all pieces and a strategy for their assembly to see the 'big picture', akin to understanding the interdependencies among various BIM process information requirements (OIR, AIR, EIR, etc.).

This analogy, along with the information management elements relationship illustrated in Figure 2.3 from PAS 1192-3, underscores the significance of strategic information management [90]. The fundamental obstacles to genuine digital transformation in the construction sector stem from procurement practices, impacting the entire lifecycle of assets and projects, as highlighted in [91]. The procurement process kicks off with the creation and specification of EIR, crucial for effective procurement and necessary for merging with contracts (from now on will due to its digital transformation will be defined as smart contracts) by transitioning files into a machine-readable format from traditional formats such as xls, pdf, doc, and dwg.

Additionally, [70] presents a method for the automatic verification of supply chain documentation and data against AIR, while [36] characterises information requirements as vital documented proof for maintaining process uniformity. This information should be consistent with the BIM Execution Plan (BEP), which is often not in a machine-readable format but can be validated against the MIDP using smart contracts. Ashworth [92], likens this process to solving a jigsaw puzzle, stressing the necessity of having all the pieces and a plan for putting them together to visualise the big picture—an analogy that mirrors the need to grasp the interconnectedness of various BIM process information requirements (OIR, AIR, EIR, etc). This comparison, along with the depiction of the relationship between information management elements highlights the critical role of strategic information management [93].

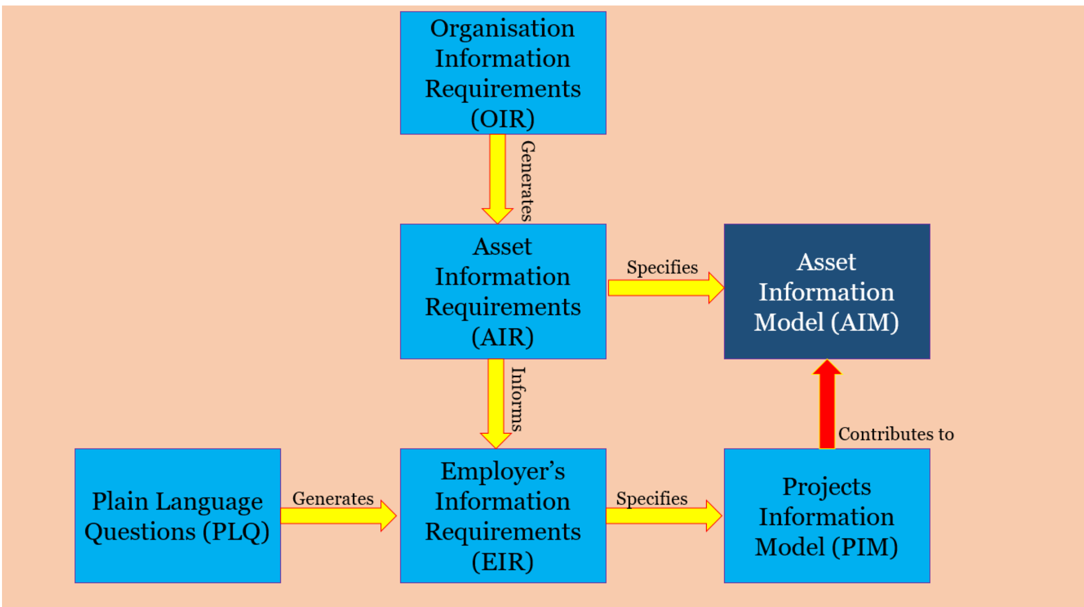

Figure 2.3: *Information Flow (Source: Adopted from ISO-19650 [2]).*

Rodriguez et al. [93], highlights that a clear EIR facilitates successful BIM adoption throughout the project lifecycle, while Carbonari et al. [94] stress early stakeholder involvement in EIR creation for BIM standards, adhering to the principle of "start with the end in mind". An example of the above is the adoption of ISO-19500 standards at KAAU highlights significant progress in enhancing the efficiency, quality, and sustainability of managing built assets throughout the AM lifecycle. The university's initiative to create a smart campus stands as a prime example of how AIM, in conjunction with Building Management Systems (BMS), could lead to advanced management of their assets. This example emphasizes the use of BMS to control and monitor the built environment's mechanical and electrical systems, integrating it with essential services like fire detection, access control, HVAC, and security cameras [95] and [96].

The strategic integration of BMS with the BIM framework proves especially beneficial in managing high-voltage generators and plant rooms, providing facility managers with detailed insights into ducts, electrical setups, and piping networks. This synergy not only aids in detailed maintenance scheduling and safety evaluations but also improves the training process for new technicians through a detailed information model [96]. Noted, KAAU's approach to adopting an open, integrated, and modular platform for its smart campus vision aligns with the ISO-19650 standards, emphasizing the importance of efficient, accurate, and secure information management across construction projects and built assets.

By mandating BMS Figure 2.4 for each asset, KAAU aims to establish a foundation for future high-level building AM, ensuring an advanced, sustainable, and efficiently managed built environment. The example of KAAU effectively demonstrates the potential practical integration of BIM with AIM and the added security benefits of Blockchain technology, and further be aligned with ISO-19650 standards. This strategic integration goes beyond meeting the immediate demands of facility management. It establishes a benchmark for developing smart campuses and managing complex infrastructure projects. By adopting this approach, there's a promise of enhanced lifecycle management, improved sustain-

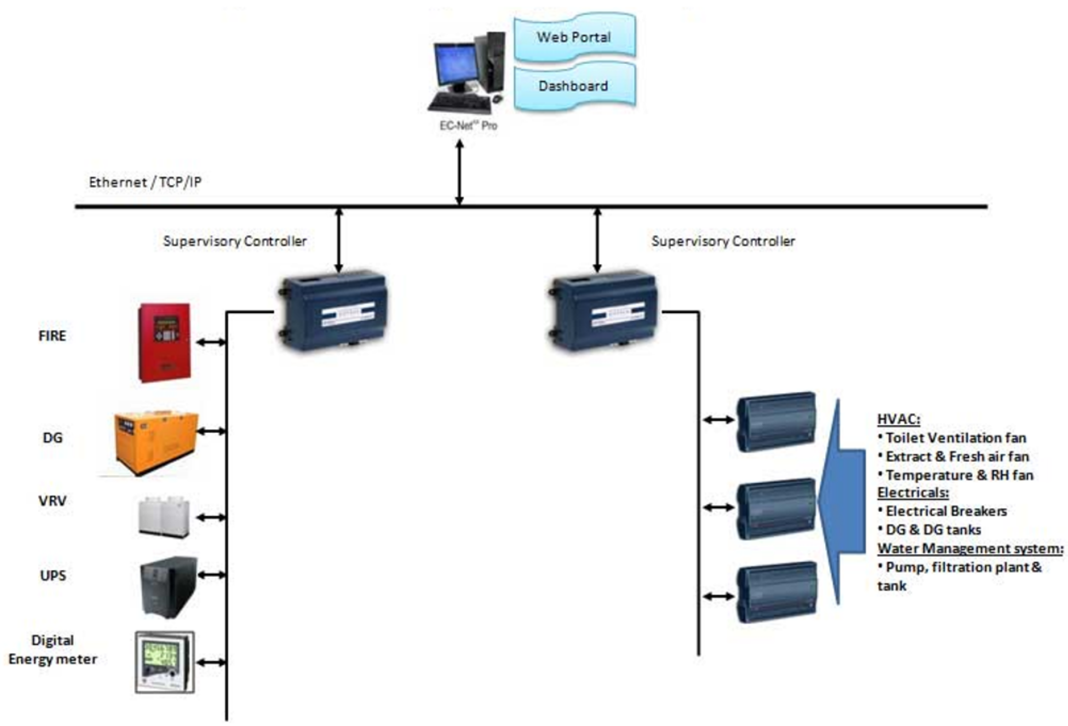

Figure 2.4: *BMS systems (Source: King Abdul-Aziz University [3].)*

ability, and elevated overall quality of built environments. This showcases not just a commitment to technological advancement but also to a comprehensive, forward-thinking management of built assets. To summarize, the fusion of BIM with AIM and the inclusion of Blockchain technology's security measures offer a holistic strategy for built AM. This methodology is reinforced by ISO-19650 standards, promoting the management of information in a way that is efficient, precise, and secure. Such management is crucial for enhancing the quality, sustainability, and lifecycle management of construction projects and built assets. The next step involves comprehending the shift from BIM to AIM, which is essential for realising the full potential of this integrated approach.

2.2.3 From BIM to AIM

AM can be defined as the coordinated activity of an organisation to realise value from assets [97]. AM has been identified in various contexts, including construction [98], transport [99], irrigation [100], and electricity [101]. It involves translating business objectives into actions, plans, and decisions through processes, tools, and techniques [97]. AIM in good practice aims to minimise risks, control costs, and enhance asset performance throughout the project lifecycle. However, implementing AM in the construction industry faces significant challenges, particularly in organisational systems and adoption, and the level of detail in information technology. Historically, AM experts concentrated on the need for communication and information technology to manage asset data and on integrating data and AM to support decision-making about assets. Previous studies have emphasised AM as a crucial factor in enhancing reliability, maintenance, and the effective use of projects [102].

AM is supported by IT software, with experienced construction firms leveraging current technology to facilitate business operations, reduce risks, save money, and improve communication within the company. AM extends beyond physical objects, encompassing the relationship between value, object, and entity. The lack of data availability can hinder AM by affecting decision-making, planning, and execution of asset activities as per ISO-19500 [2]. Thus, adopting new technologies like BIM and Blockchain is vital for supporting AM, provided BIM offers accurate data [103]. BIM should deliver information covering the entire asset lifecycle to aid in asset building, prompting the researcher to explore how BIM can consolidate all necessary information into a single file and what specific data and information relate to AM.

Integrating BIM with AM offers benefits, such as providing a clear view of long-term service and operations. Early-stage cost reductions are possible due to the availability of extensive information, and construction-stage defects can be minimised. This integration benefits various stakeholders, including clients, designers, contractors, operations and maintenance service providers, and software suppliers [36]. For clients, a comprehensive AM model enhances their AM framework and strategy, leading to maximum business value. Designers gain a clearer project understanding and the main objectives of using AM, which can reduce design time and improve technical design by aligning with the actual asset use. This alignment meets client needs and facilitates early stakeholder engagement in the asset lifecycle. Contractors gain a competitive advantage by utilizing BIM and AM, aiming to submit bids that are high in quality, timely, and cost-efficient. Hence, the early involvement of operations and maintenance providers adds value to the information model and improves asset data quality from the handover stage to the AM.

The integration of operation and maintenance teams through BIM from an early stage ensures a smooth transition at the critical handover stage [94], mitigating responsibility risks. For software suppliers, BIM serves as a foundation for model delivery, reducing technical issues and errors from unprofessional construction teams [103]. The UK's Construction 2025 [104], initiative underscores the importance of digital technology in achieving future sustainable construction industry features, highlighting the role of digital capabilities in realising whole life cycle cost savings of up to 33%. A successful handover requires a comprehensive AM model with relevant information, facilitated by the early involvement of operations teams. PAS 1192-3 outlines essential standards for AM, including defining processes and ensuring asset data relevance, structuring and documenting model data from BIM, and understanding data from internal and external perspectives. Several research papers explore the synergies and the impact of BIM and AIM integration.

Table 2.4 illustrates the main concepts of various literature items in BIM/AIM, as identified through the keyword search: When the BIM/AIM literature matrix is examined with a focus on AM, it unveils a domain where collaboration and interoperability are key themes, highlighting a movement towards integration. However, it also prompts questions about how these ideals are practically applied, especially in the face of proprietary systems and organisational hurdles.

Table 2.4: Keywords matrix of the reviewed BIM/AIM literature

AUTHORS	**Features**											
	Collaboration	*Improve quality*	*Security*	*Innovation*	*Trust*	*Share information*	*Confidentiality*	*Solve problems*	*Immutable*	*Accuracy of data*	*Materialise*	*Cryptography*
Kapogiannis and Sherratt[11]	✓			✓		✓		✓	✓	✓		
Zhu et al. [40]		✓	✓		✓	✓	✓	✓		✓		✓
Love et al.[41]	✓	✓				✓						
Chan [42]	✓	✓			✓	✓		✓		✓		
Mignone el. [43]	✓				✓	✓		✓				
Arayici and Aouad[16]	✓	✓	✓	✓		✓				✓		
Rowlinson et al.[44]	✓				✓		✓	✓				
Ilozor and Kelly [45]	✓	✓			✓	✓		✓			✓	
Pal et al. [46]	✓	✓		✓	✓	✓		✓		✓		
Abdirad and Dossick [105]		✓						✓				
Kassem et al. [15]						✓		✓		✓		
Ding et al. [47]		✓	✓			✓		✓				
Tan et al. [48]		✓				✓						
Gerges et al. [19]	✓	✓		✓		✓						
Volk et al. [49]	✓	✓	✓		✓	✓				✓		
Kelly et al. [50]	✓	✓		✓	✓	✓						

The emphasis on security and trust is paramount due to the sensitive nature of asset data. Yet, the literature suggests a gap between theoretical discussions and their real-world application in AM practices. Additionally, while the literature addresses innovation and problem-solving, there's a noticeable lack of focus on immutability and cryptography. These are essential for maintaining the integrity and security of asset data, pointing to a significant area for further research, especially in safeguarding historical accuracy and preventing data breaches. The literature acknowledges the importance of accurate data for strategic AM but falls short of detailing how to maintain data quality over time. Therefore, the matrix not only maps out the current research landscape in AIM/BIM but also identifies substantial areas for future study, particularly those that cater to the dynamic and complex needs of AM.

AM in facility management seeks to enhance efficacy and efficiency throughout the project lifecycle through a systematic approach to managing, maintaining, upgrading, and disposing of assets [70]. AIM focuses on recording all activities from the project's inception to the operation stage. Establishing, implementing, maintaining, and operating AM requires considering the project's purpose, regulatory and financial constraints, and stakeholder needs and expectations. Effective AM necessitates collaboration across the organisation to share, coordinate, and raise awareness. Linking the design and operation stages of the asset model is crucial for controlling the operation stage of the project lifecycle. Asset information processes involve actions that transform inputs into outputs [106] requiring a focus on information management to ensure proper resource allocation [30]. BIM technology supports AM by storing parameters, managing maintenance and operations, tracking the asset lifecycle, and reducing paperwork [49].

Figure 2.5 image illustrates the importance of robust information management as the link between BIM and AIM, ensuring that asset data captured during the AM cycle's initial phase effectively transforms into valuable information that aids in the long-term management of built assets.

Manage Asset Base: This represents the initial stage where the asset base is

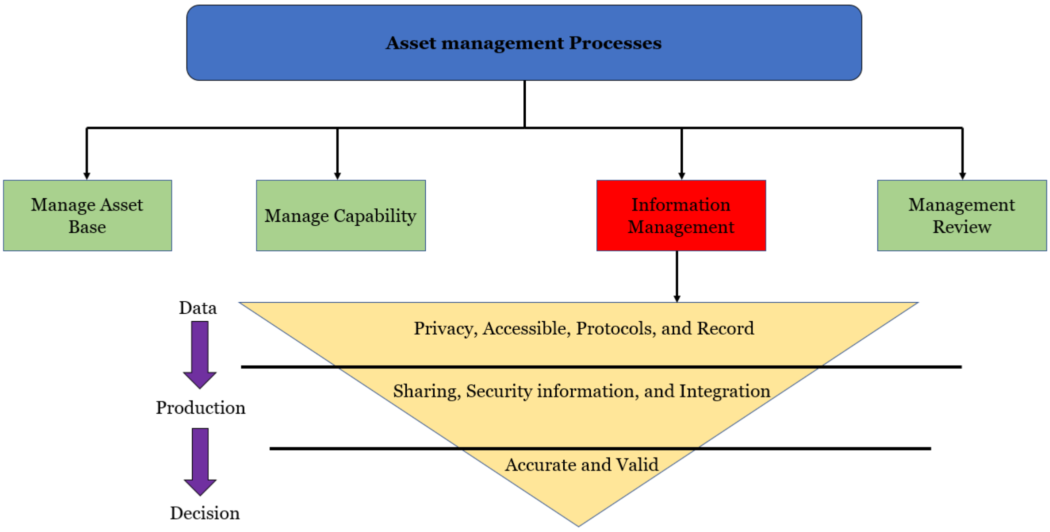

Figure 2.5: *Integrating AIM with BIM: Enhancing Decision-Making in AM Processes*

identified and managed. In the context of BIM to AIM, this could refer to the phase where the physical assets are modeled and their data is captured digitally using BIM methodologies. BIM provides detailed digital representations of the physical and functional characteristics of a facility.

Manage Capability: This step involves the management of the capability of the assets, including their operational performance and maintenance requirements. From a BIM perspective, this could entail utilizing the BIM data to understand the capabilities of various assets and how they will function within the facility.

Information Management: At the core of the diagram, and highlighted in red, is Information Management. In transitioning from BIM to AIM, this step becomes critical. It involves managing the information generated during the BIM process, ensuring privacy, accessibility, adherence to protocols, and accurate record-keeping. This data is then shared, with security measures in place, and integrated with other systems. This integration is essential for AIM, which focuses on managing and utilizing building information in the operation, maintenance, and asset management stages of a facility's lifecycle.

Management Review: The final stage involves reviewing the management practices and the overall asset management strategy. This stage is where BIM data, now part of AIM, is reviewed to ensure it meets the ongoing needs of asset management.

Within the Funnel Diagram: The Data layer at the top of the funnel indicates the collection and handling of information from BIM processes, emphasising the need for data privacy, easy access, clear protocols, and proper documentation. The Production layer signifies the operational use of this data, such as in day-to-day facilities management, ensuring that information sharing, security, and integration are handled correctly.

The Decision layer at the bottom suggests that the filtered and refined data from BIM, now within the AIM context, should lead to decisions that are accurate and valid, supporting the overall goals of asset management Henceforth, applying Blockchain from BIM to AIM could transform asset information management, rendering the system more transparent, secure, and efficient. This approach holds particular value for large-scale projects requiring dependable data access for multiple parties and where traceability and accountability are paramount. Incorporating Blockchain technology into the transition from BIM to AIM significantly improves the management, sharing, and processing of asset data. An analysis of the specific types of asset data detailed in the literature review, as presented in Tables 2.5 (building detail data), 2.6 (energy data), and 2.7 (contract management data), reveals the potential of Blockchain to bolster these data management requirements.

For Building Detail Data (Table 2.4): Blockchain can securely store and share critical information such as area/volume/address, design criteria, spare part details, manufacturer/vendor information, and asset locations. This includes the storage of installation guides, expected maintenance schedules, historical maintenance data, key plans, inspection reports, asset specifications, and operation and maintenance manuals.

This ensures that all data, from GIS coordinates to the asset's expected life and maintenance history, is immutable, easily accessible, and securely shared among stakeholders. For Energy Data (Table 2.5): The types of energy data, including the locations of control panels, electricity and water consumption records, equipment lists, and locations of valves, can be managed efficiently using Blockchain. This technology allows for the real-time tracking and transparent sharing of energy consumption data, aiding in the optimization of energy use and supporting sustainability efforts. For contract management data (Table 2.6): Blockchain's application extends to contract management by securely storing copies and types of contracts, warranty information, replacement costs, legal regulations and compliance data, purchase information, life cycle costs, certifications, and performance data. The decentralised nature of Blockchain ensures that all parties have access to up-to-date, unalterable contract details, facilitating trust and transparency in contractual obligations and compliance.

Table 2.5: Types of building detail data requirements

Type of data required	**References**	**Frequency**
Area/Volume/ Address	[57, 65, and 66]	3
Design criteria	[66-69]	4
Spare part information	[69-74]	8
Manufacturer/ vendor info	[65-71]	8
Asset location	[65-71]	11
Installation guide/date	[67-71]	9
Expected life/Maintenance history	[65-75]	12
Key plans/Asset name	[57-76]	7
Inspection report	[66-78]	8
Asset specification	[57, 66,67, 68, 69, 76, and 78]	8
Operation and maintenance manuals	[57, 68, 69, 70, 78]	5
GIS coordinates	[68-72]	4

By leveraging Blockchain technology, the data required as per the tables can be securely stored in a decentralised ledger, ensuring privacy, accessibility, and the integrity of records through smart contracts and cryptography security. This enhances collaboration among stakeholders by providing a single source of truth

Table 2.6: Types of energy data requirements

Type of data required	**Reference**	**Frequency**
Locations of the control panels	[69-71]	5
Energy consumption electricity	[54-58]	5
Equipment lists	[55-57]	4
Locations of the valves	[54-58]	5
Accessibility performance	[46-59]	2
Water consumption	[56-57]	2

Table 2.7: Types of Contract management data requirements

Type of data required	**Reference**	**Frequency**
Contract copy and type	[46-57]	5
Warranty info	[46-60]	14
Replacement cost	[46-59]	9
Legal regulations and compliance	[46-60]	6
Purchase information	[46-61]	9
Life cycle cost	[54-61]	8
Certifications	[54-61]	8
performance	[54-60]	8

for all asset data, which is especially crucial for comprehensive and accurate AM in BIM to AIM transition. The integration not only facilitates meticulous maintenance planning and health safety assessments but also supports the seamless execution of operational and maintenance activities, thereby revolutionising the management of built assets through improved transparency, security, and efficiency. Therefore, the immutable ledger provided by Blockchain technology ensures that once information is inputted into the AIM, it remains unalterable and cannot be deleted, thereby enforcing data accuracy and validity. Blockchain's security features, including encryption and decentralised verification, add an extra layer of protection to asset information, rendering it resistant to tampering and fraud.

Moreover, the implementation of smart contracts has the potential to automate numerous AM processes, leading to increased efficiency and a reduction in errors commonly associated with manual asset data handling. Consequently, the subsequent sections in this chapter will introduce deeper into the exploration of Blockchain technology and smart contracts.

2.3 Blockchain technology and Smart Contracts.

The potential of Blockchain technology to enhance the quality of reporting and significantly reduce transaction errors is noteworthy [107]. Blockchain can be conceptualised as a digital sequence of blocks, creating a ledger that is not centralised by any single individual, company, or entity—rather, it is entirely decentralised [31]. The primary innovation of Blockchain lies in its digital contract feature, also known as a smart contract [55]. This technology ensures data integrity because a) the Blockchain is replicated across numerous devices; b) once data is appended to a block, it cannot be altered; and c) the widespread distribution across many devices facilitates data sharing with enhanced privacy and security.

Turk and Klinc [27], contend that Blockchain technology will impact business and society, offering reduced reliance on central authorities and bolstering system failure protection. It promises to securely store vital records such as legal documents, governmental resolutions, certifications, and licenses—for example, land registries, birth and marriage certificates, vehicle registrations, driver's licenses, student loans, ballots, and educational credentials. Current literature primarily focuses on Blockchain's technological aspects rather than its capacity to meet social needs. Yet, recognising a new role for Blockchain could amplify its benefits and ensure the achievement of its objectives [30].

Despite the expansive nature of Blockchain literature, only a limited number of sources explore its impact within the construction sector. This gap has motivated the present study, which deems the intersection of AIM and Blockchain technology to advance the AEC industry. In detail, there are three distinct types of Blockchain: public, private, and consortium [108]; The public Blockchain allows anyone to add and verify blocks within the Blockchain ecosystem [109]. The private Blockchain restricts the ability to verify and add blocks to authorised users, though it is visible to all. The consortium Blockchain represents a semi-centralised approach where only a select group of nodes is permitted to write the block.

Figure 2.6 elucidates the Blockchain process utilised in this research, detailing the characteristics, foundational principles, and a critical perspective on various levels of application. The Blockchain comprises two principal elements: a) Non-Trusted Transaction Data (NTTD), which circulates within our database; to manage this NTTD, we require privileged participants to manipulate files and models under uniform permissions and privileges. b) Permissioned User Access (PUA) includes all system participants with equivalent permissions and facilitates a secure connection to the system database, thus enhancing database security and efficiency during any NTTD handling within the system. Blockchain technology's versatility is evident in its wide-ranging applications across sectors like finance, governance, healthcare, currency, and digital agreements [110]. In the context of AM throughout an asset's lifecycle, particularly during the operations and maintenance phase, the researcher has identified private Blockchain as an instrumental tool. This is especially pertinent when asset deterioration necessitates the acquisition of specific items by AM teams. The subsequent section will delve deeper into the intricacies of smart contracts, highlighting how they can processed and thereby enable owners to monitor their enterprises more transparently and make more informed decisions [30]. Within a Blockchain system, transactions are dispatched to different addresses via network nodes. Once these transactions are announced to the Blockchain network, it is incumbent upon other nodes to validate them based on a consensus protocol.

To maintain high-security standards, integrating Blockchain with smart contracts

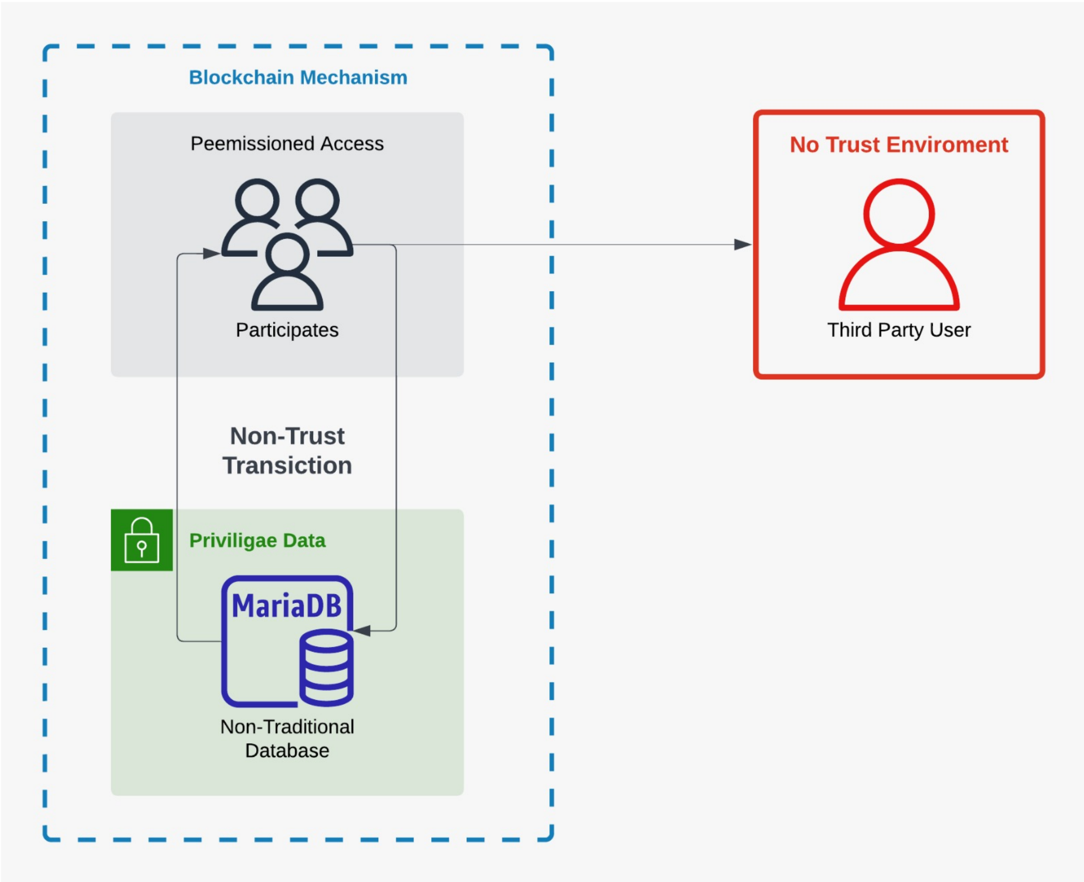

Figure 2.6: *Blockchain mechanism.*

is crucial. By looking at the literature review (table 2.8) it can be seen core benefits derived from the use of Blockchain technology.

The matrix reveals that authors have highlighted numerous benefits of Blockchain, including better collaboration, quality improvements, enhanced security, innovation, trust building, information sharing, confidentiality, problem-solving, unchangeable records (immutability), accurate data, the introduction of tangible assets (materialization), and secure encryption (cryptography). Each paper contributes to a collective understanding of how Blockchain can deeply affect the industry, showing its potential to transform and improve traditional practices and address ongoing challenges in the construction sector. The identified benefits, such as improved collaboration, higher quality, stronger security, and increased trust, demonstrate Blockchain's ability to modernise the construction industry with smart contracts, streamline operations, and tackle long-standing issues. Smart contracts represent the pioneering application of Blockchain data.

Table 2.8: Keywords matrix of the reviewed Blockchain literature

AUTHORS	**Features**											
	Collaboration	*Improve quality*	*Security*	*Innovation*	*Trust*	*Share information*	*Confidentiality*	*Solve problems*	*Immutable*	*Accuracy of data*	*Materialise*	*Cryptography*
Seebacher et al., [33]	✓	✓	✓		✓	✓		✓	✓			✓
Tama et al., [51]		✓	✓	✓	✓	✓		✓	✓			✓
Olnes et al., [31]		✓	✓	✓	✓			✓	✓	✓	✓	✓
Hileman and Garrick[52]		✓	✓	✓	✓	✓		✓	✓			✓
Lamb [53]	✓	✓		✓	✓		✓	✓				✓
Zheng et al., [28]		✓	✓		✓	✓	✓	✓	✓			✓
Zhou et al., [54]	✓	✓	✓	✓		✓		✓		✓		
Biswas et al,. [55]	✓		✓	✓		✓	✓					
Heires [56]				✓	✓					✓		✓
Turk and Klinc[27]	✓	✓	✓		✓	✓	✓		✓	✓		
Gabison [57]		✓	✓		✓		✓	✓	✓	✓		✓
Atzori [58]	✓	✓	✓	✓	✓	✓		✓		✓		✓
Saifedean [59]		✓	✓	✓	✓	✓		✓	✓	✓		
Wright et al., [60]	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
Sharples et al., [38]			✓	✓	✓	✓		✓			✓	✓
Levine et al., [61]		✓	✓		✓	✓				✓	✓	

They are composed of digital code and are stored within the Blockchain environment, offering a robust and transparent mechanism for executing contractual agreements [111]. The advancement in Blockchain technology and its application through smart contracts promise to revolutionise various industries, including construction. A smart contract can be defined as a computerised transaction protocol that automatically executes the terms of a contract when predetermined conditions are met [59]. This technology aims to satisfy common contractual conditions such as payment terms, confidentiality, and enforcement, thereby minimising the need for trust intermediaries and reducing the likelihood of fraud, arbitration, enforcement costs, and other transactional expenses.

On this basis, economic objectives associated with Blockchain's incorporation into AM include diminishing losses due to fraud, streamlining arbitration and enforcement expenditures, and mitigating various transitional costs [112]. Smart contracts epitomise a digital innovation that autonomously processes transactions upon the fulfillment of contractual terms, with no human intervention required. They are programmed in a coding language, tethered to digital currency, and are employed to represent asset payment values [59] Smart contracts stand out as one of the most significant aspects of Blockchain technology. They cultivate distributed trust within a community network, signifying that asset data is decentralised.

As defined by Peters and Panayi [112], in the context of a conceptual cryptocurrency, certain verifications are critical for the digital financial system's functionality. These include confirmation that the transaction initiator has the funds for transfer, the funds were acquired through valid means, the transaction's recipient is universally recognised as the new possessor of the funds, and the sender is no longer able to claim possession of these funds post-transaction.

The synergistic relationship between smart contracts and AIM presents several advantages for the construction sector. This includes streamlining administrative processes, minimising the necessity for legal services, and realising cost and time savings. Luo et al. [113] posit that smart contracts when integrated within a BIM model and protected via Blockchain, result in (smart construction contracts) which blend the traditional contractual agreement with the coded, self-executing clauses of the contract. However, the adoption of smart contracts is not devoid of obstacles. High initial costs for infrastructure and contract term development are notable challenges, as articulated by Lamb [53]. Stakeholders must be aware of the complete cost implications.

Smart contracts also clarify legal terms, which is invaluable, particularly when construction companies have internal legal departments to ensure all legal and regulatory requirements are met. The dearth of IT professionals skilled in Blockchain technology remains a formidable barrier to the widespread adoption of smart contracts [114]. For example, in the context of purchasing a property, a smart contract might stipulate that the buyer's payment is conditional on the seller's action of handing over the keys by a set date. Compliance results in a direct payment to the seller, while non-compliance ensures the buyer's refund. This rigidity and transparency fortify trust among parties and diminish the potential for disputes [31]. The construction industry, characterised by intricate project facets and varied stakeholder relationships, often encounters payment disputes. In 2019, the Saudi finance ministry's significant allocation of USD 19 Billion to infrastructure and transportation underscores the magnitude of such projects. This included funding for road, port, railway, airport development, and more, with a particular emphasis on Vision Realisation Programs [39]. Despite the budgetary allocations for various municipal services and infrastructural developments, the resolution to payment issues in construction largely hinges on the execution of construction contracts, which define stakeholder behavior through obligations and liabilities. Contract management becomes pivotal in this context, facilitating payment verification through transactions linked to smart contracts [115].

However, this study proposes a direct link between 'Physical Environment' and 'Blockchain Environment' via smart contracts to streamline payments once contract clauses are satisfied but not detailed discussed since this is not part of this research's objectives. Yet, challenges in implementing smart contracts persist, with information models covering a significant portion of a construction project's cost. McNamara and Sepasgozar [116] suggest that more research is needed to determine how cost models, programs, and information models can be enhanced.

Although smart contracts present a beneficial solution, they come with their own set of challenges. Once smart contracts are deployed on the Blockchain, they become unchangeable, which could endanger user privacy and inadvertently lock in confidential information permanently. Solidity, a programming language inspired by JavaScript, C++, and C, is prevalent in Blockchain and is primarily used to develop these contracts on platforms like Ethereum [117].

Smart contracts are individual programs that can operate in decentralised environments like the Ethereum Virtual Machine, where they can interact and exchange messages with other smart contracts [118]. The Web3.js library serves as a management tool for smart contract interactions, offering developers the necessary tool to execute contracts on the Blockchain [111]. The lifecycle of a smart contract within a private Ethereum Blockchain node is depicted in Figure 2.7.

As noted by Lamb [53], assuming smart contracts to be more cost-effective than conventional contracts is misleading due to the substantial infrastructure and developmental costs involved in their establishment. The implementation of smart contracts necessitates an understanding of the technology among end-users. Moreover, there is a pronounced shortage of skilled personnel within the IT sector, which not only impedes the adoption of smart contracts but also potentially strains an organisation's budget [64]. This aspect of smart contracts serves to

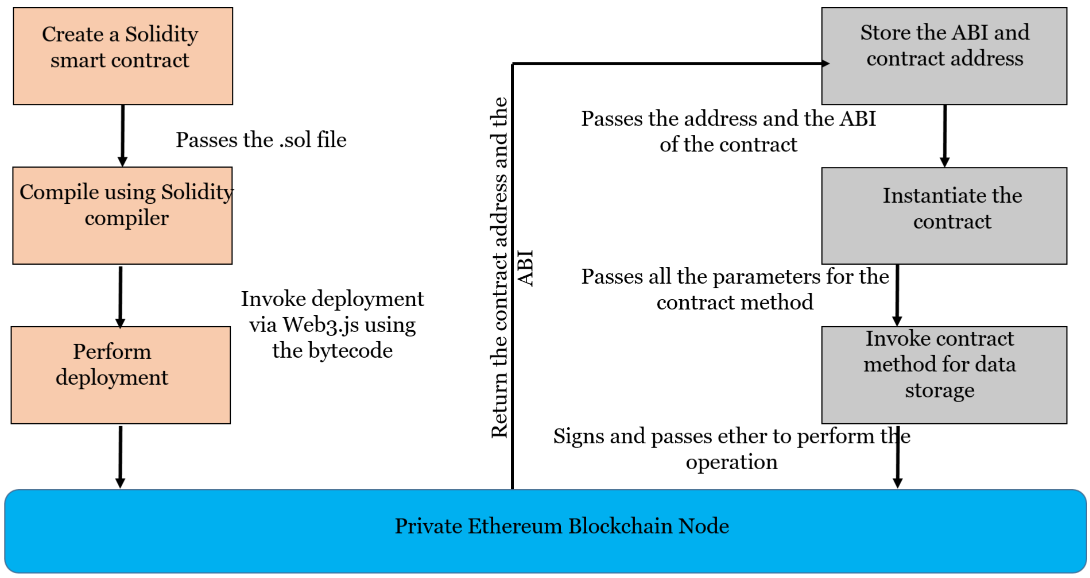

Figure 2.7: *Smart contract processes*

fortify trust and mitigate disputes between parties [31]. While the advantages of smart contracts are evident, their early deployment in projects enables Blockchain systems to collect and consolidate the necessary information for the operational phase.

In summary, smart contracts, leveraging the features of Blockchain such as collaboration, quality improvement, security, and trust, hold the potential to significantly enhance contract management and optimise BIM model usage by storing crucial data within a digital asset model. This integration facilitates the automatic validation and verification of business data, essential for supporting the operational phase of construction procurement processes. Moreover, AIM can be refined using in-house data gathered from daily site activities, thus improving decision-making by asset owners and ensuring optimal asset utilisation [91].

In essence, AIM and Blockchain stand out as innovative tools in the construction industry. They enhance privacy and confidentiality for all parties involved, such as clients, engineers, architects, consultants, and suppliers. Simultaneously, these technologies encourage greater collaboration, enabling the industry to meet the specific needs of clients more effectively. Furthermore, construction professionals are poised to develop bespoke standards for Blockchain applications, tailored to the unique characteristics and requirements of individual projects, thereby revolutionising traditional processes and addressing persistent challenges within the sector.

2.3.1 Integrating Blockchain Technology in AIM and AM: Impacts and Advances in the AM Lifecycle

In the construction sector, the integration of Blockchain technology with AIM and AM is driving major advancements throughout the asset lifecycle. This combination is meeting a critical demand for improved decision-making tools that handle data from its inception, access, storage, and alteration, to its sharing—key processes essential for the planning and design stages. Traditional industry challenges, such as the need for readily available data, efficient organisation, secure data storage, and adaptability to climate change, are being reevaluated with Blockchain's capabilities in mind [85], With the industry's acknowledgement of the progression from data to information, then knowledge, and finally to informed action [119] Blockchain technology emerges as a solution. It provides a secure, immutable, and accessible database where outdated asset information, which has long been a hindrance to effective AM, can be replaced by real-time, accurate data streams.

This innovation is particularly relevant in dismantling the silos of disjointed IT systems, offering a unified platform that can support decision-makers in dynamically adjusting to project requirements. The discourse of this work revolves around harnessing Blockchain within AIM and Management to empower stakeholders, enhancing the fluidity and reliability of information throughout the AM lifecycle.

Table 2.9 summarises the literature review between 2017-2023, which explains what information management challenges how testing was performed, and what key outcomes were achieved. This method assisted the researcher in developing testing strategies and facilitating the discussion in the dissertation's concluding section.

Authors	**Technologies used**	**Information management challenge**	**How testing was performed**	**Key outcomes**
Cavka et al., [88]	Conceptual framework	Information requirements needed to support model-based project delivery and asset management	Interviews	Handover of digital facility models
Hu et al., [120]	Automatic establishment of the logic chain	Information technology, operation information, information exchange, MEP information model	Case study	Security of the MEP system and its subsystems

Li et al., [121]	Bibliometrics approach dynamic platform	IPhysical and functional information Visualization, integration, interaction, sharing and communication,	Datasets of bibliographic records	Information system, 3D/nd modeling application, design, sustainability
Lu et al.,[122]	Green BIM Triangle	Energy, emissions, and ventilation	Green BIM	Guidance for building researchers and practitioners
Ngowtanasuwan et al., [123]	The system dynamics	Information management	Case study	Policy for BIM
Parn et al., [124]	Probability 37 density function (PDF) and the cumulative distribution function (CDF).	Clash overlap	Fact-finding, to acquire a deeper knowledge	Error mitigation
Lu et al., [125]	Analytical activity system Model	Building O and M	Interview	Map for O and M practitioners
Lee et al., [126]	Model views definitions	Data exchange	Rule logic and Ifc Doc-based BIM	Quality of received data

Xu et al., [127]	Human-organisation-technology fit (hot fit) model	Information communication, information technology, and information flow	Steeper hierarchy	Make strategic directions to better harvest the benefits of BIM
Wu et al., [128]	Blockchain-based smart Contract (BBSC) system computer protocols	Late payment	A prototype system	Management application
Shin et al., [129]	IFC-based viewer	Information management	Case study	Policy for BIM
Adel et al., [130]	Computing-oriented technology	Decision-making	A case study	Confidential data sharing
Akhmetzhanova et al., [131]	BIM Tools	Clash detection, Information exchange	Interviews	Lack of time during the design stage
Durdyev et al., [132]	Fuzzy Delphi Method	Safety and health	Framework	Hazards mitigation
Sadeghi et al., [133]	The system dynamics	Information management	Case study	Policy for BIM

van et al., [134]	A modularised, repeatable and technical solution	FM requirements	Framework	BIM data creation, adjustment, verification and transition Across the design, construction
Tao et al., [135]	Developing prototypical applications	Risks and trust problems between stakeholders	A plug-and-play framework	Increased transparency between stakeholders and a reduction of conflicts can be enabled.
Kim et al., [136]	Lightweight Blockchain	Traceability and transparency	An Ibaas prototype	Technical key solution
Chen et al., [137]	A Blockchain-enabled	Communication and information sharing.	A prototype system	Knowledge improvement
Kang et al., [138]	Blockchain technology	Data communications	A Case study	Information sharing, remove key risks

Zhong et al., [139]	Blockchain applications	Manage project workflows and uplift construction efficiency.	Semi-structured in-depth interviews	Blockchain can improve construction efficiency, reduce paper-based manual operation
Naderi et l., [140]	Blockchain-driven integration technology	Innovation for the AEC industry	A critical literature review	Technological developments And knowledge framework
Ahmad et al., [141]	An automatic incentive mechanism	Poor performance in Construction safety	Decentralized oracle network	Provides a transparent, traceable, and immutable
Ahmad et al., [142]	Blockchain-based system	Safety information systems and Accident information	Real-world construction accident data	Lead to the compilation of reliable, tamper-proof, secure, and transparent accident/ incident data;
Celik et al., [143]	Decentralised Blockchain technologies	Data security, transparency, and traceability,	Decentralised smart contracts	Decentralised, secure, trustworthy, and transparent tendering environment

Xi et al., [144]	Blockchain technology	Decreasing the likelihood of errors, mistakes, or fraudulent activities.	Simulating the smart contract	Simplicity, flexibility, And user-defined policies
Wang et al., [145]	Blockchain-enabled Cyber-physical	Managing numerous paper-based documentation, non-standardised management	A prototype system	Enhanced data submission, identity management, and data-driven site performance
Elghaish et al., [146]	Sharing Blockchain	Storage limitation and scalability	A prototype system	Solve the scalability problem
Sheng et al., [147]	Blockchain technology	Reimbursed costs, profit and cost saving	Framework: IPD-based hyper ledger fabric	Specific details, such as CA and MSP, are needed by all parties
Xue et al., [148]	Blockchain-based framework	Quality information	Prototype system and use a case study	Secure quality information management

Yang et al., [149]	Semantic differential transaction	Information redundancy in BIM and Blockchain integration	Framework	BIM can alleviate problems related to time, quality, cost, and productivity in construction.
Ahmed et al., [150]	Blockchain technology	Better communication documents sharing, stage transition and quality endorsement	Using Hyper ledger Fabric (a private, Permissioned, and open source Blockchain platform) and Ethereum	Extended transparency, traceability, and auditability
Zhong et al., [151]	Decentralised Blockchain	Poor payment practices	Smart contract payment security system	Timely and transparent payment of construction
Zhang et al., [152]	Blockchain-based framework	Quality information	Smart contracts	Mutual trust in construction quality management
Ye et al., [153]	Blockchain technology	Quality traceability	Framework	Decentralisation, openness, and non-tamper ability, as well as efficient Traceability.

Ngowtanasuwan et al., [123]	A Blockchain-based platform	Tendering information	Smart contracts	BIM development
Ye and Markus[154]	Blockchain technology	Information management	Case study	Policy for BIM
McNamara et al., [116]	Cyber-physical systems	Contract information	Literature review, Interviews	Unique and theoretical framework,
Sing [155]	Blockchain Technology	Security	Iot Application	Immutability, openness, trust, protection, and audibility.
Pradeep et al.,[156]	Blockchain technology	Information exchange	A case study	Better quality of data
Dounas et al., [157]	Decentralised web	Lack of collaboration	Ethereum Blockchain prototype	Data sharing

Table 2.9: Information management challenges from 2017-2023.

The core findings from the above table are highlighted:

1. **Digital Transformation of Information Management:** The research underscores the need for digital frameworks to support model-based project delivery and AM [88], stressing the importance of transitioning from traditional practices to digital handover models that streamline and secure the AM lifecycle.

2. **Security and Data Exchange:** There is a recurring theme on the security

of information exchange mechanisms [120], [126], [130], [136], demonstrating a growing concern for the protection of sensitive data within the industry, where Blockchain technology is seen as a potential solution to ensure the integrity and confidentiality of data.

3. **Facilitating Efficient Operations:** Utilisation of system dynamics models [123], [133] and Blockchain-based smart contracts [128], [151], [152] indicates a drive toward more efficient, transparent, and reliable operational processes in construction projects, with an emphasis on improving the trust and communication among stakeholders.

4. **Quality Information Management:** The research identifies the use of Blockchain to secure asset data quality [148], suggesting that the immutable nature of Blockchain could be a significant factor in mitigating errors and improving the reliability of asset documentation.

5. **Blockchain's Role in Overcoming Traditional Challenges:** The literature reveals that Blockchain applications are being explored to address traditional industry challenges such as clash detection [124], late payments [128], and risk management [135] stating that Blockchain could reduce conflicts, enhance stakeholder transparency, and provide a more robust incentive mechanism for safety [141].

6. **Impact on Stakeholder Collaboration:** Decentralised Blockchain technologies are discussed in the context of fostering better collaboration and data-sharing practices [143], [149] suggesting that Blockchain could resolve issues of data redundancy and facilitate a more cooperative approach to AM.

7. **Information Traceability and Transparency:** Several studies emphasise the potential of Blockchain for improving traceability and transparency [136], [140], [141], which are crucial for real-time tracking and verifiable change management throughout the asset lifecycle.

8. **Enhancing Decision-Making and Policy Development:** The research points to the capability of Blockchain to support decision-making and policy development for BIM [123], [129], [140] suggesting that Blockchain's attributes can underpin the strategic directions necessary for leveraging BIM technologies.

9. **Addressing Scalability and Integration:** Research focusing on Blockchain-enabled cyber-physical systems [145] and Blockchain sharing [146] highlights the necessity to address scalability challenges and the management of vast quantities of paper-based, non-standardised documents. These studies advocate for a more sophisticated data-driven strategy to improve site performance and facilitate integration across different platforms.

10. **Innovation and Efficiency in Project Workflow Management:** Blockchain applications are recognised for their capacity to manage project workflows, reduce manual paper-based operations [139], and foster innovation within the AEC industry [140], signifying that Blockchain can potentially streamline processes and improve construction efficiency.

These core findings reflect an emerging consensus on the transformative potential of Blockchain technology to address longstanding challenges within the construction industry, particularly in the realms of information management, data security, and stakeholder collaboration. The literature indicates a positive trajectory toward more decentralised, transparent, and efficient AM practices, supported by Blockchain's inherent capabilities as it is presented in Figure 2.8.

2.4 Discussion

In concluding the literature review for this Ph.D. thesis, it is apparent that the intersection of BIM, AIM, and Blockchain technology holds considerable potential for revolutionising the construction industry, particularly in the enhancement of the AM lifecycle. The literature reviewed has collectively highlighted a spectrum

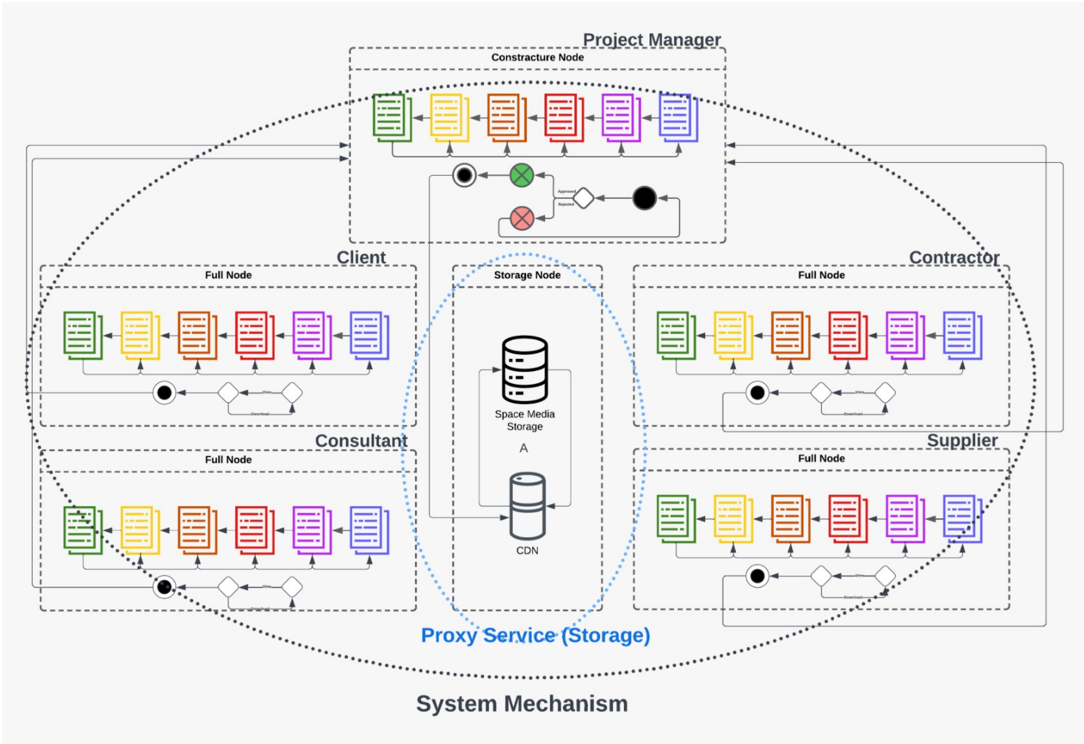

Figure 2.8: *Research gap and system mechanism*

of technological advances and methodological applications.

However, a discernible research gap persists in the consistent and comprehensive documentation of asset project data throughout an asset's lifecycle. This gap manifests as a bottleneck in the efficient handover of project data, where issues such as inconsistent data storage, the volume of project data, collaborative practices, contract management, and secure information sharing remain largely unaddressed. The integration of Blockchain technology emerges as a potent solution to these challenges, bringing to the fore its strengths in decentralisation, security, and traceability. This integration is poised to provide a fundamental improvement to AIM and BIM processes, ensuring more reliable management of lifecycle data throughout the asset lifecycle.

The research endeavors to fill this gap by introducing a Blockchain-based environment, leveraging a private Azure Blockchain platform to test a system that enhances data analysis across AM stages. This system is expected to refine model management, from uploads and downloads to clash detection and conflict resolution, and tackle issues related to data, fragmented model exchanges, multiple data model formats, and data security. The anticipated outcomes of this research included strengthening decision-making processes for project owners, asset, and maintenance teams, building stronger trust among stakeholders, and ensuring the accuracy of data for handover processes.

Additionally, the research aimed to streamline the development of comprehensive and integrated AM systems, enhance collaboration among stakeholders, and accelerate the fulfilment of client investments. Therefore, this research proposed a synergistic approach where the robustness of Blockchain complements and amplifies the information-rich capabilities of BIM and AIM, offering a significant paradigm shift that could serve as a benchmark for future research and practices in the AM domain.

2.5 Summary

This literature review chapter comprehensively explores the critical role of BIM and AIM in the construction sector, elucidating their synergistic potential when integrated with emerging technologies like Blockchain. The chapter commenced by delineating the significance of BIM execution plans in facilitating collaborative workflows and streamlining decision-making processes across the asset lifecycle. Furthermore, it delved into the international standards governed by ISO-19650, illuminating their capacity to address prevalent challenges within the Saudi construction industry, such as contractor expertise gaps, ineffective planning, and inadequate communication.

The chapter then navigated the transition from BIM to AIM, underscoring the criticality of robust information management in transforming data captured during the asset lifecycle and better managed. This transition is facilitated by the

principles of AM by ISO 19500, which aim to optimise asset performance, minimise risks, and control costs throughout the project lifecycle Blockchain technology emerges as a solution, with the chapter carefully dissecting its architectural underpinnings, including its decentralised nature, immutability, and consensus mechanisms.
The review explains the multilateral classification of Blockchains – public, private, and consortium – while explaining the rationale for advocating the private Blockchain model within the context of AM throughout the AM Lifecycle. Moreover, the chapter delves into the intricacies of smart contracts, illuminating their potential to automate processes, enhance transparency, and mitigate disputes within the construction sector.

It navigated the lifecycle of smart contracts, highlighting the role of programming languages like Solidity and tools like Web3.js in their deployment and interaction within the Ethereum Virtual Machine. The integrative approach of consolidating Blockchain technology within AIM and AM was then explored, underscoring its capacity to address foundational challenges within the industry, such as data availability, organisational efficiency, secure storage, and climate change resilience.

The chapter culminated by explaining the transformative impacts of this integration across the AM lifecycle, dismantling siloed IT systems, and fostering a unified platform that empowers stakeholders with real-time, accurate data streams for dynamic decision-making. Overall, the literature review chapter presents a comprehensive and scholarly exploration of the synergistic convergence of BIM, AIM, Blockchain technology, and smart contracts, illuminating their collective potential to revolutionise the construction sector through enhanced collaboration, security, immutability, and data integrity. Building on this foundation, Chapter 3 delves into the research design and methodology, outlining the approaches taken to investigate these technologies' impact on the AEC industry empirically.

Chapter 3

Methodology

3.1 Introduction

Previous chapters have extensively covered the literature review and related work. The literature review discussed what has taken place in studies in terms of AIM and Management, BIM, Blockchain, and Smart Contracts. These two chapters have greatly contributed to the research work and methods to be used, given the nature of the questions to be answered using the chosen theory. This chapter details the methodology of the study based on the purpose and objectives. The research methodology is intended to describe how this study will be conducted using the chosen methods. Detailing the research methodology involves outlining the specific procedures, techniques, and approaches that will be utilized to conduct the study. In this regard, it substantiates the logic for using the deductive approach in the positivism philosophy. The rest of the chapter is structured as follows: The next section explains the research design.

Section 3.3 contains the research methodology and the procedures to understand what constitutes reality and knowledge (ontology and epistemology). Section 3.4 covers the research sample. Sections 3.5 and 3.6 cover research limitations and ethics procedures. Finally, section 3.7 contains a summary of the chapter. This structured approach ensures that each section of the methodology chapter is clearly defined and addresses specific aspects of the research process.

3.2 Research design

Researchers play an important role in confronting the challenges of knowledge in any field. Research is the foundation of scientific knowledge, and the representation of others' work [158]. The researcher has been deeply influenced by Kapogiannis [159], [1], [160] and [161], to plan and prepare the research at a methodical level to attempt to achieve the aim of this work. Research can be defined as, *'the act of finding something you do not know and to reorient our thinking, to make us question what we think we do not know, and to focus on new aspects of our complex reality'* [162]. Research allows us to investigate and discover a new concept and to improve and add knowledge to an existing idea. Good research solves a practical problem and answers a specific question, which will lead to explaining and creating an understanding of the concept and intent to explore it. According to the Economic and Social Research Council, research is *'To contribute to a body of knowledge or theory'* [163].

Also, research is a *'structured set of guidelines or activities to assist in generating valid and reliable research results'* [164]. Phenomenology research can be defined as *'letting things show themselves'* [165]. Therefore, solid research has a clear definition for the methodology and strategy, with all the findings able to be validated and tested. In addition, the methodology must have unique characteristics to be truly scientific, which must investigate and define the research problem, design an appropriate method, then gather adequate data, and demonstrate research outcome and results [166]. Research processes are defined by Sekaran [167], as a continuous, overlapping process to explain, compare, and predicate theories and general concepts. Traditionally, there are two types of scientific research: applied and pure.

Figure 3.1 illustrates the typical process of carrying out scientific research. Furthermore, the research aims and objectives will allow the researcher to consider a process that includes the following aspects: planning research, analysis and data collection, and reporting of final results. According to Walliman [1] the application of the correct research method and approaches will achieve actual results and new knowledge.

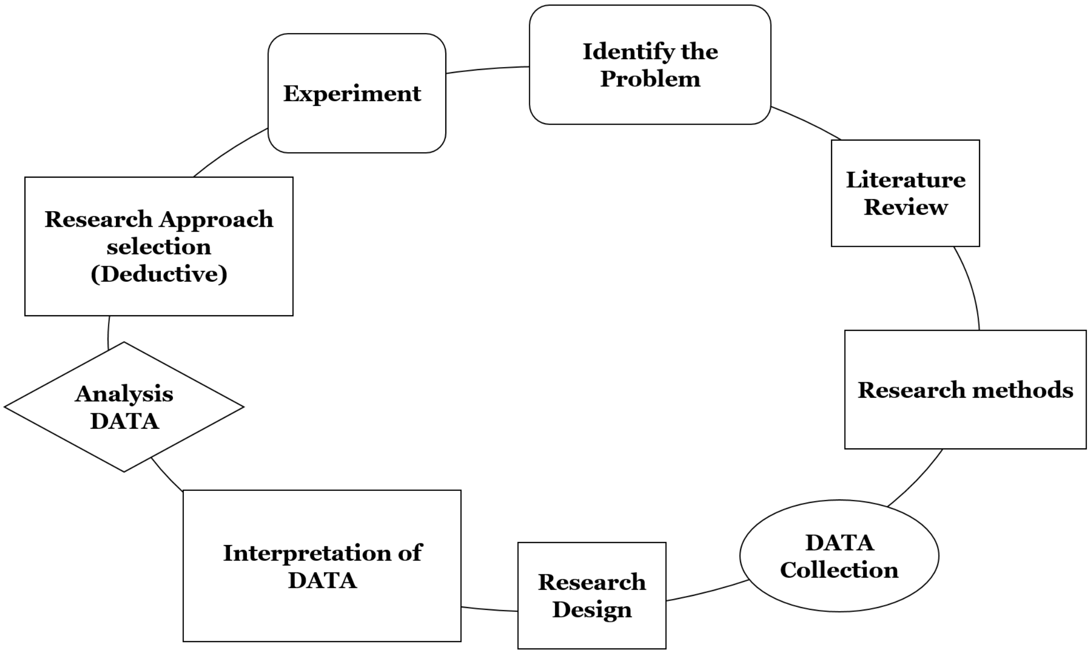

Figure 3.1: *Typical scientific research (Source: Adopted from [1])*

Kapogiannis [159], stated that the most difficult part of research is the determination of assumptions to clarify and identify the research aim and objectives. Consequently, to design and plan the research to answer research questions Table 3.1 below provides the main philosophical questions: The research methodolog-

Table 3.1: Philosophical questions to be answered (Source: Adopted from [1].)

Questions	Definition
What is knowledge?	Ontology
How do we understand the knowledge?	Epistemology
What is the contribution to the knowledge?	Axiology
The procedures of learning knowledge	Methodology

ical framework and methods are the essential components of any research that must be explicitly explained to show the path the research will take. Although methodology and methods are quite often used interchangeably to mean the same thing they are distinct from each other although are used to denote essential procedures in the research process.

According to Bryman [168], a methodology contains philosophical stances a researcher wishes to follow and the methods that are used for data collection. Crotty [169], defines the research methodological framework as, *"the research design that shapes our choice and use of particular methods and links them to the desired outcomes What is called here for is not only a description of the methodology but also an account of the rationale it provides for the choice of methods and the particular forms in which the methods are employed".* According to Teddlie and Tashakkori [170], research methodological framework is, *"a broad approach to scientific inquiry specifying how research questions should be asked and answered. This includes world view considerations, general preferences for designs, sampling logic, data collection and analytical strategies, and the criteria for assessing and improving quality".*

Research that has no clear assumptions regarding world view or adhering to particular methods used to collect data might not provide useful results. It is from this understanding that this study wishes to describe the worldviews and thereafter explain the view that will lead it as well as describe the methods that will be used in the process of data collection and analysis. With this understanding in mind, this study aims to elucidate various worldviews and subsequently articulate the perspective that will guide its approach. Moreover, it intends to outline the methodologies employed for both data collection and analysis. Accordingly, O'Leary [171], states *'methodologies are crucial to the research process for the knowledge production, they show the outside world that we are not just random people with an opinion, but we are researchers who are engaged in a rigorous process and that we have grappled with the responsibilities and controversies associated with knowledge production'.*

Teddlie and Tashakkori [170], and O'Leary [171], emphasise the role of methodology; with particular emphasis on the discussion about philosophical assumptions followed in the study. The two philosophical assumptions that are discussed to address issues of methodology and methods lie in ontology and epistemology views. According to Walliman [1], being aware of these philosophical assumptions helps to guide the researcher thoroughly about what views will be relied upon in the course of making research results and the conclusion reached truly representative of the research data itself. The researcher used a hypothesis-based approach that was built up over a literature review.

3.3 Research Methodology

A research methodology is a systematic approach employed by the researcher to organise and execute their investigations aimed at addressing specific research questions or testing hypotheses [172]. This involves a series of steps and techniques for collecting, processing, and analysing data in a precise and reliable manner. The primary focus of this research is to employ quantitative methods through experimental designs for effective data collection, specifically targeting asset owners in KSA. Hence, the researcher used a hypothesis-based approach over a literature review process.[173], [160], and [160], and a workshop (descriptive statistics) to understand the current challenges in AM within the context of the KSA. This work aims to investigate whether and how Blockchain and AIM can be the future facilitators of the construction project lifecycle and, thus, optimise the owner's ROI. This research proposes a practical tool improvement that would make Blockchain and AIM attractive options to be used to achieve the research objectives. The research objectives, set in Chapter 1, were:

1. **Exploration of Blockchain and AIM Synergy:** to examine how Blockchain technology enhances AIM integration within the AM lifecycle and to understand its broader implications for the field of AM.

2. **Development and Validation of an AIM-Blockchain Tool**: to design, develop, and systematically validate a Blockchain-based tool that is integrated with AIM, aimed at streamlining the AM lifecycle, and to evaluate the expected outcomes of its real-world implementation.

3. **Assessment of Blockchain's Added Value with AIM**: to investigate the additional benefits Blockchain technology brings when combined with AIM in the AM lifecycle, mainly how it boosts operational efficiency, improves data safety, and fosters stakeholder collaboration.

Table 3.2 gives a total overview of the research methodology including methods, data collection – analysis, and interrelation with the research questions and objectives.

Table 3.2: Research Methodology AIM and Blockchain Technology in AM

Objective	Activity	Method	Sample	Data Analysis	Chapter
1	Literature Review	Literature Review	Multi trailer	Thematic Analysis	Chapter 2
2	Workshop to test the Blockchain-based tool for asset managers	For the beta test a survey was shared	5 Team Members	Descriptive Statistics	Chapter 4
3	Workshop was run to understand the impact factor analysis affecting the operation of the asset life cycle by using AIM and Blockchain technology	Multi-quantitative method was used	37	Descriptive Statistics	Chapter 5

The information in **Table 3.2.** is provided for the following context:

- **Research Topic:** The research topic is clearly defined, focusing on the integration of AIM and Blockchain technology in the asset lifecycle.

- **Research Scope:** The scope is precisely delineated, targeting asset management in KSA. It considers the perspectives of clients, contractors, and project consultants to thoroughly understand the research problem. The emphasis on the execution, handover, and operation stages of the construction project lifecycle aligns well with the research questions and objectives.

- **Review Literature:** The purpose of the literature review is articulated, aiming to elucidate the interrelationship between AIM and Blockchain in assets. Additionally, it seeks to enhance the efficiency of the asset management lifecycle by utilizing AIM and Blockchain.

- **Formulate Research Objectives:** The research objectives are specific, encompassing the definition of key concepts, exploration of Blockchain's added value during the asset management stage, and the design and validation of a Blockchain-based tool.

In detail, this methodology is intended to shed light on the intricate relationship between AIM, BIM, and Blockchain technology within the asset lifecycle, directly aligning with **Objective 1** [171]. Moreover, the researcher to be able test thoroughly examine how the interplay between AIM and Blockchain has prompted construction companies to actively participate in the evolution of construction technology and information model management in KSA [172]. This examination is crucial for understanding **Objective 2**, which focuses on assessing the technological influence on construction management practices. To this end, the research uses as a case study a current project in the KSA, concerning a diesel generator project that utilised a design and build procurement approach. This setting provides a concrete example to explore the practical implications of AIM and Blockchain in real-world asset management processes [171].

Hence, by adopting Yin's case study design [160], the research aims to answer critical 'how' questions while considering the relevant contextual conditions that are significant to the phenomenon under investigation. This methodological approach is instrumental in achieving **Objectives 1 and 2**, by facilitating an in-depth understanding of the roles and perspectives of construction experts regarding AIM and Blockchain activities. In addition to the above, the researcher aims to employ a multi-method experimental design to delve into the subjective experiences of participants, thereby gaining insights into the impact of AIM and Blockchain on asset management within the KSA construction industry.

As a matter of fact, this aligns with Objective 3, as it involves validating the technological impact through a practical assessment. In particular, the study will leverage a deductive approach to explore the commonalities in reasons behind construction companies' engagement with AIM and Blockchain technologies. This approach not only aids in meeting Objective 2 by enhancing our understanding of complex technological applications in construction but also contributes to Objective 3 through the analysis of experiment responses and the broadening of comprehension regarding the impact of AIM and Blockchain on asset management within the KSA construction industry. Finally, the initiative to design and test a Blockchain-based environment for assessing the impact on the asset lifecycle marks a direct approach to fulfilling **Objective 3.** This effort is complemented by the formulation of sub-questions aimed at evaluating the influence of AIM at various stages of the asset management lifecycle, thus providing a structured framework to explore the potential of Blockchain and AIM as key facilitators in optimising asset management.

3.3.1 Research Methods

Research methods mean *"the techniques or procedures used to gather and analyse data related to some research question or hypothesis"* [169].

According to Walliman [1], methods are divided into two: *"the methods of data collection and methods of data analyses".* This section aims to describe straightforward procedures to collect data from different sources using different methods, followed by a description of the techniques of analysis, qualitatively. The philosophical position of the research is that a positivism paradigm will be applied to explore and uncover the reasons why construction companies apply AIM and Blockchain KSA. The positivism approach is about using data collected for the interpretation of the meanings of the cases investigated as opposed to mathematical generalisation [174]. To undergo the positivism, approach the study will use a case study seeking identification and explanation with the aim of a wider understanding of why certain practices such as BIM and Blockchain are needed [175]. The phenomenon and nature of data collection methods of participatory observation are primarily aimed at achieving an understanding of individuals and their life worlds [160].

According to Berg and Lune [174], *"in the life-worlds, researchers focus on naturally emerging languages and the meanings individuals and groups assign to experience"*. In line with this contention, the study will extract information with appropriate meaning from perception and work experience of the relationship between BIM and Blockchain in the construction industry. The positivism paradigm is relevant for this study because it will provide a broader understanding of the phenomenon under investigation from the perceptions, behavior, and work experiences of participants [176].

3.3.1.1 Case Study Design and Beta Testing:

Integration of Blockchain Technology with AIM in the Female Driving School Project at King Abdul-Aziz University Incorporating the specified phases into the case study of the beta test for the Blockchain-Enabled AIM environment offers a detailed narrative of the project's lifecycle from inception to evaluation. This comprehensive methodology unfolds as follows:

1. **Requirements Collection:** Initiating the project, this phase established

the critical requirements for Blockchain's effective integration with AIM. Insights gleaned from literature reviews, client feedback, and consortium experts contributed to a robust foundation for the subsequent development of the provenance framework, pivotal for the beta-test set.

2. **Mixed Research:** This phase encompassed a thorough investigation that leveraged both qualitative and quantitative data, drawing from case studies, scholarly articles, and best practices within the industry. The aim was to craft a nuanced understanding of Blockchain's potential and real-world application in the construction domain (linked to Chapter 2).

3. **Data Consolidation:** Upon gathering extensive research data, the phase involved consolidating and analysing this information to shape AIM data models and scenarios. This step ensured the Blockchain application was appropriately tailored to the specific requirements and intricacies of the construction sector (linked to Chapter 2).

4. **Experimental Testing:** An experimental Blockchain environment was established using tools such as Remix Ethereum and the Azure Blockchain network. This stage was crucial for hands-on testing and validation of the theoretical models devised from the research phases, with the beta-test involving asset management professionals assessing the system's real-world effectiveness. (Appendix C for details/Chapter 4). Figure 3.2 below describes the user interaction with a document management system that is enhanced with Blockchain technology, emphasising the varying levels of access and control across different user roles and the integration of typical document management functions with Blockchain-specific actions. The detailed system's architecture is presented in Chapter 4.

5. **Development of Smart Contracts:** Leveraging Solidity, the phase involved the creation of smart contracts that encapsulated the project's provenance functionalities. These smart contracts served as actionable Blockchain

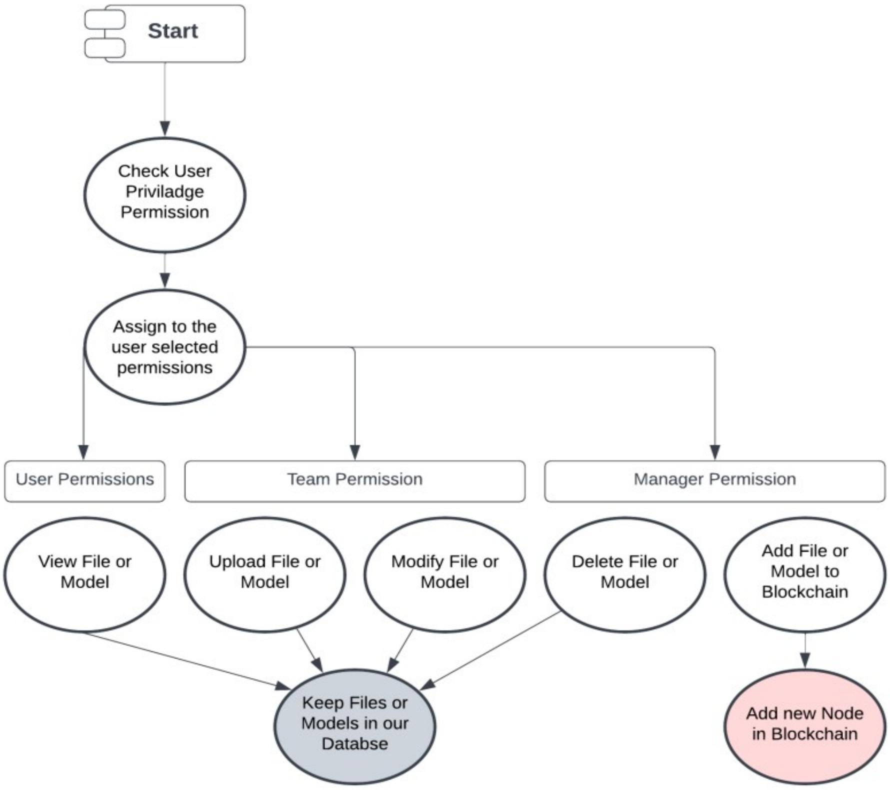

Figure 3.2: *System Methodology Diagram.*

components that would drive the AIM framework within the actual handover stage of the construction project(Appendix C for details/Chapter 4).

6. **User Interface Development:** A user-friendly interface was developed for effective interaction with smart contracts, enhancing user experience and adoption rates. This interface allowed asset managers to efficiently visualise AIM, upload EIRs, and confirm the Blockchain framework's integration. (Appendix C for details/Chapter 4).

7. **Results and Evaluation:** The final phase involved presenting and assessing the outcomes of the AIM-Blockchain integration scenarios. This evaluation was crucial to demonstrate the connection's efficacy for data storage and to showcase the feasibility of the Blockchain-AIM link using a fully coordinated model throughout the asset lifecycle (chapter 4).

In summary, the case study's narrative is rounded out by the integration of a technological framework that adhered to a multi-layered approach reflective of the OSI model. The beta test was pivotal in verifying the system's architecture, which was designed to cater to the complex requirements of asset management across construction projects. The architectural components—ranging from the User Confirmation Module to the Blockchain Server—were meticulously developed to support the various user roles and ensure secure data flow and document validation. Moreover, the researcher designed and developed the Blockchain-based tool, assuring compliance with international standards like ISO-19650 and ISO-55000. Using a combination of programming languages, the tool aimed to support technical and security standards, providing a solid foundation for the research study's objectives (chapter 1).

3.3.1.2 Validation - Impact of AIM and Blockchain Technology in the Asset Lifecycle

At the final stage, the researcher ran a workshop attended by a total of 37 independent asset owners to validate the impact of the proposed Blockchain–based tool to support throughout the AM lifecycle: design, construction, operations, and maintenance. The workshop was conducted in November 2020 to explore the integration of AIM and Blockchain technology within the asset lifecycle, focusing on its potential for sustainable development in KSA. The workshop aimed to gather insights from various stakeholders in the asset management sector, including contraction teams and groups, to discuss the current state, challenges, and opportunities presented by the adoption of AIM and Blockchain technologies (objective 3, Chapter 5).

Subsequently, a survey was administered to the group of experts using descriptive statistics to evaluate the impact of project delivery on the efficiency of operating AIM models and management. The findings provided compelling evidence of the influence of operational AIMs across various stages of the asset management lifecycle, along with potential results. More details about the workshop can be found in Appendix B and Chapters 5 and 6 in more detail. Finally, to test the sub-questions, mean value analysis, and Chi-square hypotheses test were used to ensure reliability. For data validity, Cronbach's alpha test was used [177].

3.4 Sampling Procedures

For **Objective 1**, the research delved into the vast landscape of existing literature, exploring the realms of Blockchain Technology, BIM in construction, and the intersection of AIM and Blockchain. Notably, the researcher honed in on the context of the KSA due to two primary factors: firstly, the prevalent challenges in data and information management within KSA hinder effective asset management using digital models and technologies; secondly, there exists a notable inconsistency and transformation of information between project handover and the facility management team during the operational stage.

For **Objective 2**, a select group of 5 team members from a company were invited to participate in validating the Blockchain-based tool. This tool was put to the test through a case study conducted. The objective was to assess the operational feasibility of Blockchain technology in dynamically accommodating changes during asset operation. To facilitate this assessment, three sub-questions were developed, each corresponding to different stages of asset management. This allowed stakeholders such as owners, consultants, contractors, and suppliers to engage in activities such as uploading, visualising, reviewing, selecting, and deciding on the best course of action based on the asset information model, particularly during the tendering stage facilitated by smart contracts. The system methodology diagram adopted for this purpose is illustrated in Figure 3.2, which shows the systematic approach undertaken in this study, aligning closely with the objectives outlined in Section 1.4.

For **objective 3** the size of the organization was the criterion for selection used in the experiments (large organisations) which are located in the KSA Makkah region. The General Authority of Statistics shows the total number of enterprises of a large company which refers to 1034 companies (General Authority of Statistics, 2022).

The researcher looked at the number of registered qualified engineers in the KSA, then obtained data from the Saudi Council of Engineering (SCE) to determine the proportional sample to be collected and for the research to be validated according to SCE has 429247 registered members. The researcher needs to gather 96 responses given that the population size is 429247 qualified Engineers and IT, the confidence level is 95%, and the error is 10 %. Therefore, the SCE has published the flyer on its website and the researcher has sent the workshop flyer via email and social media applications. A total of n=37 responses have been received, with a 95% confidence level the responses (data – answers) are accurate with an error level to be 12.7%. An experimental study has been used as part of a workshop to facilitate a learning point, the study intends to conduct 1 participatory observation to validate the impact of BIM/AIM/Blockchain Technology.

3.5 Research Limitations

This research has been conducted as a case study in the construction industry of the KSA although the findings may apply to other contexts or countries. The primary objective was to improve the operational processes of asset management and to enhance current practices through the application of the acquired knowledge. A significant challenge faced in the adoption of BIM and Blockchain technologies in the construction industry is the limitation of skilled personnel. Moreover, a principal obstacle to the implementation of Blockchain, AIM, and BIM is the issue of cost.

This stems from the clients' reluctance to adopt new technologies in their businesses and projects, as the ROI for AIM and Blockchain remains unclear from the asset owners and other stakeholders. Nonetheless, the data collection methods and data analysis approaches have been elaborated upon, clearly explaining the multi-method approach to be followed.

3.6 Ethics Procedures

Ethical considerations are a fundamental attribute that must be observed throughout the research process, encompassing data collection and the dissemination of results. This is crucial to protect the values and integrity of the participant companies or individuals [1].

As this study employs data collection methods involving human participants, utmost care must be taken to safeguard the participating companies and individual managers [178]. Before commencing data collection, the researcher will obtain clearance from the University of Nottingham's ethical approval committee, ensuring that all appropriate measures have been taken for the data collection process in Saudi Arabia. The researcher will first request permission from the company's management to conduct a workshop, followed by seeking consent from the individual participants [179]. However, the researcher acknowledges and respects the participants' right to excuse themselves from participating in the surveys or workshops. The information collected from all participants will strictly adhere to ethical guidelines and will not be disclosed for any purpose other than the stated research objectives [179].

Similarly, the confidentiality and privacy of participants will be maintained by treating all collected information with the utmost discretion and respect for their dignity. Participants' identities and names will remain undisclosed during the participatory observation process. Where names are required, pseudonyms will be used to protect their anonymity [179]. Furthermore, confidentiality will be ensured through the secure custody of all collected information, with transcribed hard copies stored in the University of Nottingham's secured lockers. Any digital information will be stored on the University of Nottingham's or the researcher's personal computers, protected by password-secured encryption. These measures aim to uphold the highest ethical standards and maintain the integrity of the research process while respecting the rights and privacy of all participants involved.

3.7 Summary

This chapter has described extensively the research methodology and methods. Firstly, the different philosophical perspectives regarding social science research were examined, followed by the choice of the philosophical position of this study. Secondly, data collection methods were described, and the selection of a multi-method approach of semi-structured interview and participatory observation has been discussed about their philosophical position.

To summarise, the research process can only be guided by a well-defined research focus and technique, which guarantees that the study is thorough, morally sound, and advances the field's understanding. Choosing a methodology for conducting a study should be supported by a clear justification that considers the goals of the study, its viability, previous findings, theoretical frameworks, and ethical concerns about the study. Integrating AIM and Blockchain technology in construction projects is a relevant and timely topic, and the proposed research has the potential to contribute to theoretical and practical knowledge in this area.

Chapter 4

IT Prototype

4.1 Introduction

This chapter delves into the high-level architecture and operational mechanics of a Blockchain-based AIM system, specifically tailored for the management of assets within the construction sector. By introducing a robust, user-oriented platform that facilitates the secure and efficient handling of asset data, this research explores the intersection of cutting-edge digital ledger technology and traditional AM methodologies. The focus of this chapter is to present a comprehensive analysis of the system architecture that underpins this innovative approach, providing insight into the layers of interaction, security protocols, and data flow management that ensure the integrity and reliability of asset information followed by a beta test. The results of this chapter lead to the next stage of the research methodology (Chapter 3) to validate the impact factor analysis on the operation of the AM lifecycle utilizing the integrated AIM and Blockchain system in Chapter 5.

4.2 Research Method

In the realm of AIM within construction, the research method employed focused on deploying and beta-testing a high-level architecture of a Blockchain-based system, complemented by an AIM interface [147], [180]. The architectural framework included a multi-layered approach aligned with the Open Systems Interconnection (OSI) model, emphasising secure and structured data flow between user roles and blockchain services [181], [182]. The system architecture was designed to support the complex needs of AM throughout the lifecycle [183],[182], [184], [185], and [186] This involved the development and integration of several key components:

1. A User Confirmation Module (UCM) to handle diverse user types, from BIM/AM managers to suppliers, and manage their registration, system login, and subsequent access privileges.

2. The AIM Blockchain System operates as a repository and verification hub for AIM files, with approval mechanisms and re-upload services.

3. A robust Blockchain Server for the secure transfer of approved documents to the blockchain, ensuring data immutability.

On this basis, the research methodology is linked to the Data-Information-Knowledge-Wisdom (DIKW) hierarchy, a conceptual framework that outlines the transformation of raw data into wisdom through various stages [187]. The connection is discussed by analysing each component of the system and identifying its role within the DIKW hierarchy as can be seen in detail below:

Data Layer (Data): At the base of the DIKW pyramid, data consists of raw, unprocessed facts. In this context, the blockchain system architecture captures raw data through the AIM interface, which collects detailed information on construction assets [188]. This data is unstructured and uninterpreted, serving as the foundation for the next layers [180].

Information Layer (Information): Information is derived from processing data to add context, relevance, and purpose. The User Confirmation Module and the AIM Blockchain System act at this level. By managing user types and access privileges, the system organises raw data into a structured form. The AIM Blockchain System further processes this data, providing a repository and verification hub for AIM files [188]. This involves organising data into meaningful patterns like approval mechanisms and document status transforming it into information that's accessible and useful for decision-making [30].

Knowledge Layer (Knowledge): Knowledge involves the application of information to formulate insights, decisions, or predictions. Within the described methodology, knowledge is represented by the integration of the Blockchain with the system architecture, emphasising secure and structured data flow between user roles and blockchain services. The system's ability to verify and approve AIM files before they are uploaded to the blockchain reflects the application of information to ensure data integrity and reliability [188]. This ensures that only accurate, verified information is used to make decisions or insights about construction AM [189].

Wisdom Layer (Wisdom): Wisdom is the highest level of the hierarchy, representing the ultimate use of knowledge to make sound decisions with a deep understanding of the implications. While the described methodology primarily focuses on the lower layers of the DIKW pyramid, the strategic implementation of a multi-layered architecture, with an emphasis on security and structured data flow, lays the groundwork for developing wisdom. Over time, as users interact with the system, learn from the data, and make increasingly informed decisions regarding construction AM, the collective wisdom of the organization is expected to grow [188]. This wisdom enables stakeholders to not only make more effective decisions but also to anticipate future challenges and opportunities within the construction industry [180]. In summary, the research methodology described for deploying a blockchain-based system for AM exemplifies the DIKW hierarchy by systematically transforming raw data into structured information, then applying that information to generate knowledge, and ultimately aiming towards the development of wisdom in managing assets effectively.

Building upon this foundation, the methodology was applied to a case study at the Female Driving School project, hosted by the University of KAAU in KSA. This real-world application involved a beta test with five AM professionals who evaluated the system's performance. Key aspects under scrutiny included AIM visualisation, Exchange Information Requirements upload and validation, along the seamless integration of AIM within a Blockchain framework. This evaluation underscored the significance of accurate and real-time AM, bolstered by an AIM system that encompasses comprehensive documentation, data, and graphical models, highlighting the transformative potential of Blockchain technology in AM.

The system's architecture encouraged collaborative efforts among stakeholders, enabling updates and modifications in alignment with BIM standards and Industry Foundation Classes (IFC) specifications. This collaborative environment [8], supported by the blockchain's inherent security features and decentralisation, provided robust protection against cyber threats [188], while still achieving high system performance. This approach directly addressed the prevalent challenges within the Saudi construction sector, characterised by informal information exchanges and a lack of structured communication. The Blockchain-enabled AIM Environment revolutionised the management of assets by offering a well-structured and operational information system. This system not only clarifies specifications but also aims to enhance awareness across all stages of the asset lifecycle. Through this innovative application, the project demonstrated the substantial benefits of Blockchain technology in AM, marking a significant step forward in addressing the specific needs of the construction industry in the domain of AM.

4.3 System Architecture

The introduction to a Blockchain-based AIM system integrates a sophisticated system architecture, a two-tier web application, and a comprehensive integrated system architecture diagram to illustrate the dynamic and secure management of construction assets. This system leverages Blockchain technology to ensure data integrity, immutability, and security [188], making it a robust solution for the complex needs of AM in the sector. Below it is outlined the key components of this system:

Blockchain-Based AIM System Architecture: At the heart of this system is a Blockchain-based architecture designed to manage and secure asset information. This architecture utilizes the immutable nature of Blockchain technology to ensure that all data related to construction assets is verified, transparent, and proven. By integrating with an AIM interface, the system facilitates the structured and secure flow of data between various stakeholders, enhancing accountability and efficiency in AM processes [183].

Two-Tier Web Application: The system features a user-friendly two-tier web application, which serves as the primary interface for users to interact with the AIM system. The first tier, the client side, offers an intuitive user interface for accessing, submitting, and managing AIM files and related documents. The second tier, the server side, handles the processing, storage, and retrieval of data, acting as a bridge between the users and the blockchain. This two-tier architecture simplifies the user experience while maintaining a high level of security and data integrity [190].

Detailed Integrated System Architecture Diagram: To provide a clear understanding of the system's operation and integration points, a detailed integrated system architecture diagram is included. This diagram visually represents the relationships and data flow among the system's components, including the user confirmation module, the AIM blockchain system, and the Blockchain server. It illustrates how these components work together to manage user roles, verify and approve AIM files, and securely transfer approved documents to the blockchain. The diagram serves as a roadmap for understanding the system's functionality and its robust architecture.

Overall, this introduction sets the stage for a detailed exploration of a cutting-edge solution to AIM in the construction industry. By harnessing the power of

Blockchain technology and integrating it with a user-friendly web application, this system offers a secure, efficient, and transparent way to manage assets throughout their lifecycle.

4.3.1 Blockchain-based AIM system integrated Architecture (High Level)

The system architecture is depicted in image 4.1. outlines a Blockchain-based AIM system integrated with user role management and a re-upload service for rejected files [191]. Figure 4.1 presents a diagram explaining the system's framework. It shows the system's boundaries, user roles, and permissions. The diagram also illustrates how users interact with the system, from logging in to registration. It details the activation process for new users by the system manager. Users are assigned roles with specific permissions, like uploading, viewing, or commenting on files. There's a process for approving files and moving them to the handover stage. At this stage, the project manager uses blockchain to encrypt the files.

Finally, a secure download link is sent to the customer's email. The diagram integrates various system log-ins for different user types (like client, consultant, contractor, and supplier) and connects these elements to describe how the system operates. The layout is for illustrating system architecture, user interactions, and data flow within the Blockchain–enabled AIM system. The system's architecture is designed to ensure a streamlined process for AIM with clear roles for different stakeholders and an immutable record of files/models stored on the Blockchain [144]. This supports the processes of verification, approval, and revision within the context of AM in the construction industry, reinforcing data integrity and traceability [191].

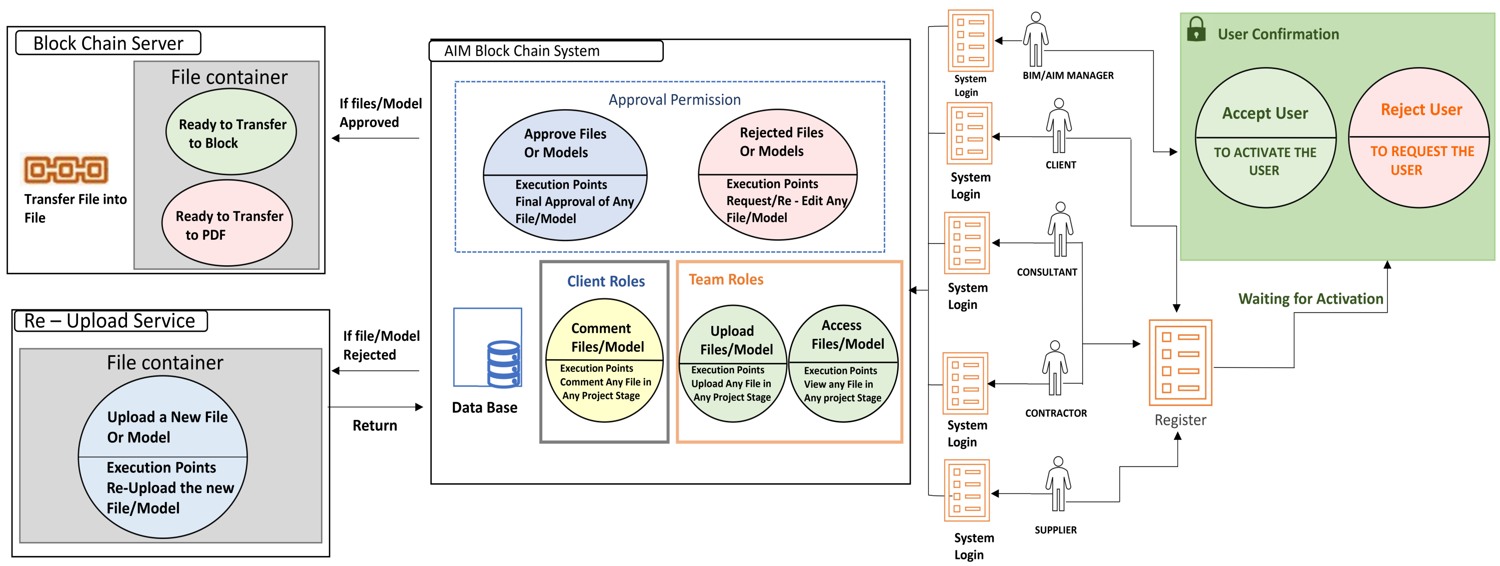

Figure 4.1: *System Dynamics Diagram.*

The researcher used the OSI model as a guide [192], the following outline of the system architecture (figure 4.1.) in terms of layers, focusing on the interaction between user roles, Blockchain services, and data flow.

1. **Application Layer:**
   - User Interface: Interface for BIM/AM Manager, Client, Consultant, Contractor, and Supplier for registration and login.
   - Handles file conversion to PDF for approved documents.
2. **User Confirmation System:** Manages user registration, activation, rejection, and login processes.
3. **AIM Blockchain Interface:** Where users interact with the file container for approving, commenting, and uploading files.
4. **Presentation Layer:**
   - Data Formatting: Converts files ready for transfer into Blockchain or PDF format based on approval status.
   - Encryption/Decryption: Ensures that data transferred between the client application and blockchain is securely encrypted.
5. **Session Layer:**
   - User Sessions: Handles the creation, management, and termination of sessions for different user roles during their interactions with the system.
   - Transaction Management: Oversees transactions for file approvals or rejections, ensuring consistency and reliability.
6. **Transport Layer:**
   - Data Transfer: Manages the end-to-end data transfer processes, error handling, and flow control for file uploads and downloads.

7. **Network Layer:**

    - Routing: Directs data packets through the network, determining the optimal path for data transfer between the user applications and the blockchain server.
    - Addressing: Assigns IP addresses for identifying devices and managing the data routing.

8. **Data Link Layer:**

    - Frames Management: Organises data into frames for transmission, handles frame synchronisation, and controls access to the physical medium.
    - Error Detection and Correction: Ensures that frames sent to the blockchain are error-free using checksum and acknowledgments.

9. **Physical Layer:**

    - Media and Signal Transmission: Deals with the actual transmission of the data over network media, whether it's wired or wireless, handling the bit-level communication.

In the study, a deployment diagram is utilised, which is a form of a Unified Modeling Language (UML) diagram.

This diagram is referred to as Figure 4.2 and it details the execution architecture of the system. It covers both the tangible hardware and the intangible software components that support the system's operations, along with the middle ware that establishes connections between them. The diagram explicitly illustrates the deployment strategy of the system across the primary and subsidiary servers, and it clarifies how these servers communicate with each other using HTTP (Hypertext Transfer Protocol)/HTTPS Hypertext Transfer Protocol Secure) web protocols.

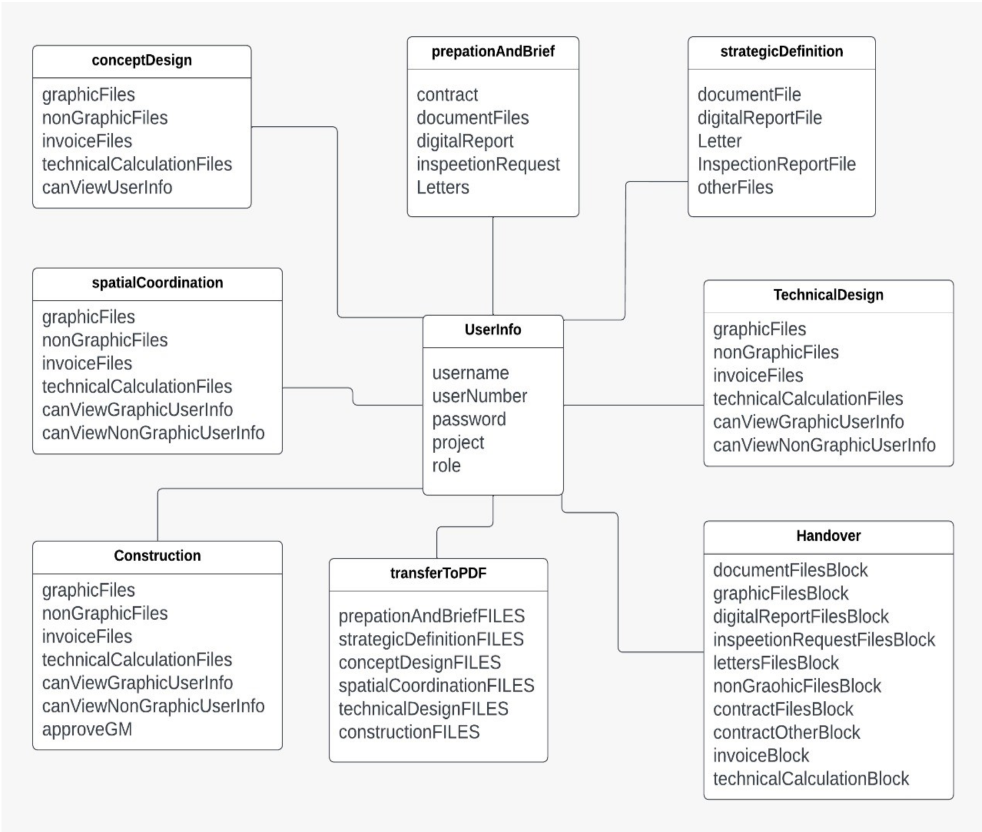

Figure 4.2: *Deployment Diagram.*

In detail, the deployment diagram is designed through various system nodes, representing stages or functionalities within the AM project. For instance, nodes like "concept design" and "spatial Coordination" handle different types of files relevant to their respective phases, from (non) graphic designs to technical calculations. The "Construction" node specifically addresses the project phase, incorporating a mechanism for managerial approvals. Further nodes like "Preparation And Brief" and "Strategic Definition" are repositories for preparatory and strategic documents, crucial in the early and planning stages of AM. "Technical Design" and "Handover" correspond to later stages, where technical specifications are detailed, and project handover is facilitated, with an indication of Blockchain usage for secure file handling. "User Info" and "Transfer To PDF" nodes point to system functionalities about user authentication and document management.

Together, these components interlock to form an intricate AM system, encapsulating the document and file management workflows as visualised in the deployment diagram that incorporates Blockchain technology for enhanced security and version control, especially noted in the context of “blocks” for the handover phase [180].

4.3.2 Web application- A two-tier architecture

For the deployment of the web application, a two-tier architecture was required [192]. Figure 4.3, as observed, provided an overview of the components in the deployment scenario:

1. **System Application Server:**
   - Running on an Ubuntu execution environment.
   - Uses Nginx as the web server and reverse proxy.
   - Hosts a Django Server, which is a Python web framework that follows the MVC (Model-View-Controller) architecture.
2. **Data Application Server:**
   - Also running on an Ubuntu execution environment.
   - Utilises Nginx for the web server.
   - Connects to a MySQL database that stores the application’s data.

Communication between these servers was facilitated through HTTP/HTTPS protocols, suggesting a web-based application architecture that compartmentalised the back end (Django Server) and the database server (MySQL). The Django server was tasked with managing the application logic, user interactions, and model management. In contrast, the MySQL server was devoted to data storage and retrieval tasks [191].
The researcher designed the system’s architecture by choosing Rationalised Data Base Management System (RDBMS) which ensured the data was stored and managed in a way that was compatible with the project’s needs [186]. The chosen two-tier architecture served as the essential framework for the Blockchain-based

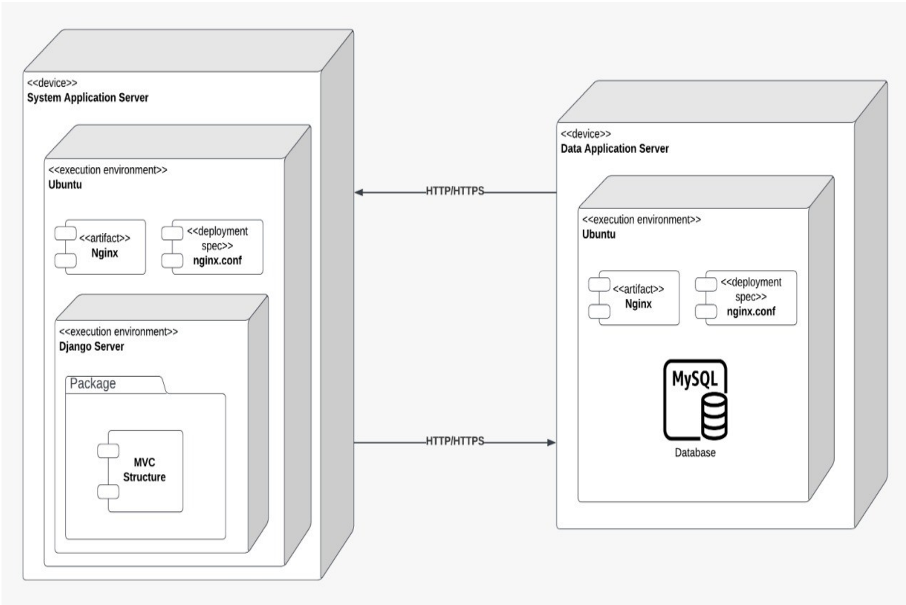

Figure 4.3: *Data Model.*

AIM system. Within this architecture, the System Application Server played an important role, with the Django server at its core. This server was responsible for the workings of the AIM system, including validating user identities, organising files, and managing the flow of transactions—all critical for integrating with the blockchain. The Data Application Server's MySQL database was the storage workhorse, keeping detailed records of transactions, user profiles, and file information. These pieces of data are the lifeblood of Blockchain operations, and the MySQL server ensured they were kept safe and sound. Serving as the system's gatekeepers, the Nginx servers on both application servers managed the influx of queries and outgoing responses. Whether it involved processing by Django or fetching data from MySQL, Nginx ensured smooth and secure access to the system's resources.

The integration of the three key components—the Django server, the MySQL database, and the Nginx servers—culminated in the development of a cohesive and reliable system. This system transcended being merely a repository of information; it evolved into a dynamic environment underpinning the necessary infrastructure for a robust and secure AM system, augmented by blockchain technology. In essence, the described two-tier architecture offered vital support for the operational requirements of the Blockchain-based AIM system.

It provided a fortified, scalable, and secure platform for hosting the web-based application and managing the related data effectively.

4.3.3 Detailed Integrated System Architecture diagram

The Technical Details diagram, referred to as Figure 4.4, outlines a comprehensive system architecture, specifying the technologies and frameworks employed in each component.

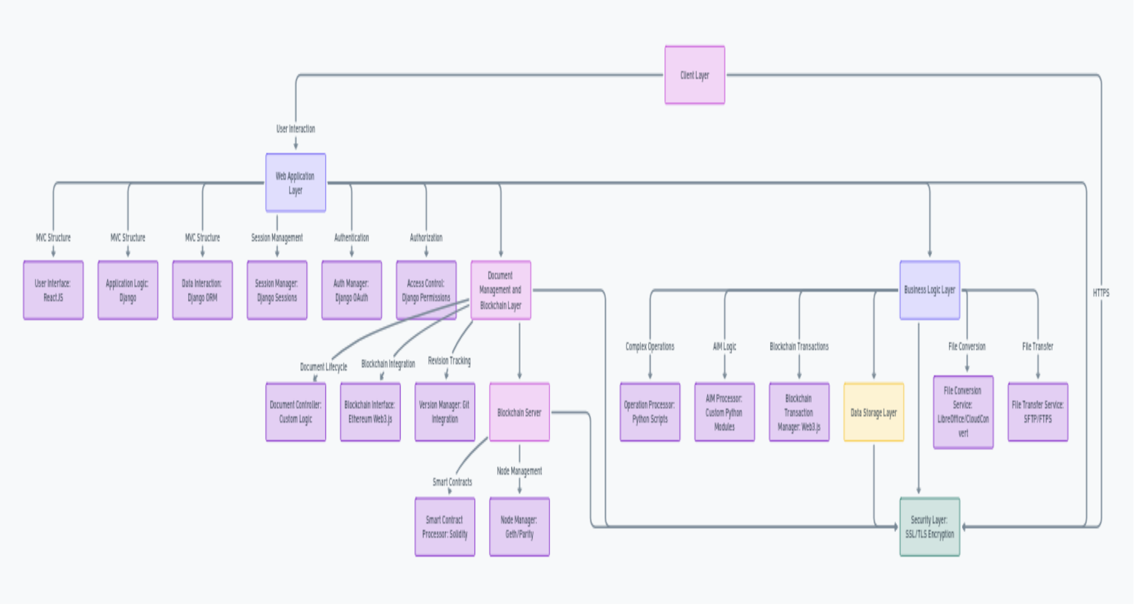

Figure 4.4: *Integrated System Architecture and Technological Framework*

Here's an explanation of the architecture and the details of the various technologies involved:

Client Layer User Engagement: The first point of contact for users is an interface, likely leveraging web technologies such as HTML, CSS, and JavaScript, with potential enhancements from frameworks like React or Angular. Mobile interfaces are presumably developed using Swift or Kotlin.

Web Application Layer Dynamic Interaction: At this layer, the MVC architecture is brought to life by the Django framework, offering a seamless operational flow:

- **User Interaction:** Reactive and responsive elements are crafted with ReactJS.
- Application Logic: Core functions are coordinated by Django, steering the application's operations.
- Data Interaction: Database communication is facilitated by Django's ORM, bypassing the need for manual SQL.
- Session Management: Django also manages user sessions, providing continuity across user requests.
- Authentication and Authorization: User identity is secured by Django OAuth, while access is managed by Django Permissions.
- Document Lifecycle Management: A custom logic system handles the various stages of document management.
- Blockchain Interface: Ethereum's Web3.js library is harnessed to interact with the blockchain for immutable record-keeping.
- Revision Tracking: Document history and revisions are tracked meticulously through integration with Git.

Database Management Structured Data Storage:

A relational database, MySQL, forms the foundation for storing essential data, ranging from user information to transaction logs, all organised within a relational structure.

Blockchain Server Decentralised Validation:

The Blockchain server utilizes smart contracts written in Solidity for document verification and access control, while node management software like Geth or Parity facilitates connection to the Ethereum network.

Security and Communication Ensuring Data Integrity

The architecture emphasises security across all layers with SSL/TLS encryption, protecting data from unauthorised access or alteration.

File Conversion and Transfer Facilitating Document Flow:

- File Conversion Service: Documents are converted to required formats using tools like LibreOffice or Cloud Convert.
- File Transfer Service: Secure transfer protocols ensure that files are safely moved between the web application and the blockchain server.

In essence, Figure 4.4 describes an ecosystem where each technology plays a key role, integrating to create a secure, efficient, and user-centric environment. This system is designed to support the robust and secure management of a Blockchain-enabled AM platform. This architecture integrates traditional web application structures with the innovative use of Blockchain for document management, ensuring a secure, efficient, and user-friendly system for managing AM lifecycles and transactions in a decentralised manner. Hence now is the stage of testing the new Blockchain-based environment.

4.4 Implementing the Blockchain-Enabled AIM Case Study

Background: In the city of Jeddah within the Makkah region, the KAAU has embarked on an ambitious project to establish a Female Driving School. The project leverages a design and build procurement method, involving key stakeholders Modern Cities Engineering Consultant (MCEC) as the main contractor and Cummiens Arabia (CA) as the supplier. At the handover stage, the deliverables include comprehensive AIMs comprising graphical models, non-graphical data, and supporting documentation [193]. A more detailed presentation of the validation can be found in Appendix C.

Challenge:

The primary challenge was to ensure the secure, transparent, and efficient management of asset information throughout the asset lifecycle. This required an innovative solution to handle the graphical and non-graphical models and extensive documentation associated with the project's AIMs.

Solution:

The Blockchain-Enabled AIM Environment: A system architecture was designed and implemented to address these challenges:

1. **User Interface/Application Layer:**

    - Provided a platform for project stakeholders to interact with the system, including facilities to create new projects, manage project forms, and access the project action page.

2. **Web Application Layer (Django/Python):**

    - Managed the business logic and served as the interaction layer for all stages of the project from strategic definition to the handover stage.
    - Processed and managed asset information, including graphical models, non-graphical data, and documentation, ensuring consistency and adherence to project specifications.

3. **Blockchain Interaction Layer:**

    - Secured the AIMs by recording the transactions and the document states onto the blockchain, ensuring data integrity and facilitating the audit trail.
    - Handled the conversion of AIMs into blockchain records during the final handover stage, ensuring that all deliverables were immutable and traceable.

4. **Data Storage Layer (MySQL):**

- Stored all non-graphical asset information and user data, interfacing with the web application layer for data retrieval and updates.

5. **Project Stages (0-5):**

   - Systematized the project into discrete stages to facilitate monitoring and quality assurance.
   - Enabled stakeholders to navigate through various project phases, from creating a project (Stage 0) to the strategic definition upload (Stage 3) and beyond.

Outcome: Upon project completion, the Blockchain-Enabled Asset Information Modelling Environment had successfully processed and stored all AIMs relevant to the Female Driving School at KAAU. The system provided MCEC and CA with a seamless, secure platform for managing and handing over the project's AIMs. This included graphical models, non-graphical data, and a full suite of documentation. The blockchain layer added a novel dimension of data security and trust, as each AIM became an immutable record upon handover. This not only enhanced the integrity of the asset information but also provided KAAU with the assurance of having a transparent and unalterable record of all project assets.

Validation: A focused team of five AM experts conducted a beta test of the Blockchain-Enabled AIM Environment, assessing the practicality and efficacy of the system's capabilities. The AIM, crucial for AM and operations, comprises three integral components: documentation, non-graphical data, and graphical models. During the beta test, the platform was evaluated for its capacity to facilitate a real virtual environment where stakeholders, including the client's representative and asset manager, could interact, upload, and verify the EIR and AIM. Details on how the prototype operates can be found in Appendix C how the prototype operates can be found.

AIM Visualisation and EIR Upload: The virtual interface allowed for the visualisation of AIM in a simulated operational context. Stakeholders were able to navigate the system with ease, uploading the EIR and viewing the integration of the AIM within the blockchain framework. The visualisation process was not merely about graphical representation but also included the ability to cross-reference EIR data with current updates, ensuring the AM was accurate and in real-time. The beta test demonstrated that the EIR — encompassing detailed specifications of a backup electric generator unit — could be matched and verified against predefined criteria within the decentralised application (DApp) platform, enhancing collaboration across all stages of the asset's life cycle.

Solidity/ Java Script Implementation: Technical code written in Solidity/JavaScript was used to develop the validation processes within the DApp platform. This system was engineered to automatically compare supplier inputs with EIR parameters, with criteria such as generator capacity, voltage, cycles, and revolution speeds being instantly validated upon exact matches. The smart contract underlying this process was rigorously tested to ensure accurate validations and automatic data matching between the EIR and the post-contract-award BIM Execution Plan (BEP) before the digital handover of the asset information model [189].

AIM Model and AM Integration: The AIM model was expanded to include not just the primary data sets but also additional AM information. The integration allowed for the use of multiple software applications like CAD, SketchUp, and Revit to handle diverse file formats, ensuring the concept and design were fully dimensional and compliant with the National BIM standards and IFC specifications. This integration facilitated the collaborative approach advocated by BIM, allowing stakeholders to insert, extract, update, or modify information supporting their roles. More details can be found in the 4.1 table below:

Security and Decentralisation: In the beta test, ensuring the system's security was a top priority [194]. The test successfully demonstrated the blockchain's robust defense against typical cyber threats. Thanks to its high degree of decentralisation, stakeholders gained trust in the resilience of the system. The design carefully considered the balance between decentralisation and performance, en-

Table 4.1: Code Snippet Interpretation Table

Section	Language	Description
Pragma Directive	Solidity	Specifies that the Solidity compiler version.
Imports	Solidity	Two files are imported: $remix_tests.sol$‘‘ for testing in the Remix IDE, and a custom contract file ‘ballot. sol‘.
Contract Declaration	Solidity	Declares an Ethereum smart contract named ‘AIM‘.
EIR Value Check	Mixed	A function (seems like pseudocode, not standard Solidity) checks if form values meet certain conditions related to an electric generator’s specifications.
Alert for Mismatch	JavaScript TypeScript	If form values do not match the expected conditions, an alert $'EIRnotmatch!'$ is displayed.
EIR Creation Service Call	JavaScript TypeScript	Calls a service ‘createEIR‘ with the form data and handles the result asynchronously.
Error Handling	JavaScript TypeScript	If ‘$res.isSuccess$‘ is ‘$false$‘, it shows an alert with ‘$res.message$‘ and navigates to a different route/page in the application.

suring that the system remained effective and secure without sacrificing speed or efficiency [30].

Addressing Data Accuracy and Collaboration: The new system addressed the participants’ challenge of informal information delivery by providing direct access to encrypted files from anywhere, at any time. This accessibility significantly enhanced IT utilisation among construction teams [11].

The Blockchain-Enabled AIM Environment established a formal and operational information system that spanned from strategic definition to in-use stages. It ensured clear specifications and boosted awareness throughout the entire asset lifecycle.

Visualisation and Testing Compliance: The system’s virtual environment was designed to enhance the project’s comprehension and presentation by displaying documentation in diverse formats, including three-dimensional graphical models. This advancement in visualisation significantly improved stakeholders’ ability to interpret the project’s intricacies visually. It featured specific snapshots captured using tools such as SketchUp, CAD, and Revit, which provided both external and internal views of the project. These views were meticulously focused on the geometric details of the construction, particularly emphasising the generator unit's design and installation to ensure it met regulatory standards. This detailed visual representation facilitated a deeper understanding of the project's scope and requirements, enabling more informed decisions and discussions among team members and stakeholders.

DApp and User Identity Security: The DApp (Decentralised Application) platform introduced an innovative method for users to interact with the system securely, providing them with autonomy over their personal data. Leveraging the cryptography keys provided by blockchain technology, users gained the ability to manage their digital identities confidently. This approach emphasised the importance of understanding and mitigating the risks associated with the security of private keys, a concern that is well-documented in contemporary research. Through this platform, users could engage with the digital environment, assured of their data's integrity and the safeguarding of their privacy.

4.5 Beta Test

A group of five AM professionals convened at KAAU to engage in a beta test of the Blockchain-Enabled (AIM) Environment. This initiative aimed to investigate the transformative capabilities of Blockchain technology within the realm of AM. Through diligent testing and a meticulously structured workshop, the research team embarked on a quest to identify both the strengths and areas necessitating enhancement in the proposed Blockchain-based AIM platform.

Core Benefits Highlighted The thematic analysis of feedback from the beta test revealed several key advantages of the Blockchain-based system:

- Enhanced Collaboration: The platform promoted a high degree of cooperation among participants, facilitating smoother project coordination and decision-making. Quality Improvement: Users noted a marked enhancement in the quality of AM operations, attributable to the data integrity features of Blockchain.

- Increased Data Security: Blockchain's secure ledger system offered a strong layer of protection for sensitive asset information.
- Fostering Innovation: The incorporation of Blockchain into AIM spurred innovation, motivating the pursuit of novel AM strategies.
- Building Trust: The inherent transparency of Blockchain greatly bolstered trust among all involved parties.
- Efficient Information Sharing and Confidentiality: The system adeptly managed the balance between seamless information exchange and the confidentiality of sensitive data.
- Effective Problem-Solving: The precision and accessibility of data expedited the resolution of issues.
- Accuracy, Materialisation, and Cryptography: The platform was commended for its accurate data capture, secure storage solutions, and robust cryptography.

Challenges and Areas for Improvement The beta test also shed light on several technical hurdles and areas ripe for improvement:

- File Compatibility Issues: Participants encountered constraints regarding the file formats that could be uploaded, leading to delays. Initially, the system inadvertently allowed mp4 files, which was not intended.
- Knowledge Gaps: A notable demand emerged for increased awareness and comprehension of BIM/AIM and Blockchain, especially concerning the utilisation and advantages of the platform.
- Interoperability Concerns: The platform's failure to support IFC files underscored the necessity for enhanced interoperability to more effectively manage asset information and models.

Recommendations and Next Steps In response to the feedback, the following measures were suggested to refine the Blockchain-Enabled AIM Environment:

- Comprehensive Training: Formulate targeted training modules on BIM/AIM awareness, Blockchain technology, and the operational intricacies of the new system to bridge identified knowledge gaps.

- System Improvements: Execute technical modifications to enhance file format compatibility, user interface intelligibility, and overall system interoperability.

- Reassessment and Validation: With the proposed adjustments in place, a strategy was devised to reevaluate the system's influence on asset managers within KSA, aiming to verify the improvements and further assess the system's advantages.

The beta test at KAAU, despite the obstacles encountered, highlighted the considerable potential of Blockchain technology to revolutionise AM. The collaborative process of gathering and acting upon feedback has charted a definitive course for refining the platform, to amplify its contributions to creating a more secure, efficient, and cooperative AM ecosystem. Adopting an iterative method of development, feedback collection, and reassessment ensures that the Blockchain-Enabled AIM Environment will continually evolve to meet the fluctuating demands of the AM sector, signifying a substantial advancement in integrating Blockchain technology with AIM. After spending two months rectifying the identified bugs, the researcher proceeded to validate the impact of the proposed Blockchain-Based AIM platform, marking a significant milestone in its development journey (Chapter 5).

4.6 Summary

In conclusion, this chapter has detailed the creation, implementation, and testing of a groundbreaking Blockchain-based AIM system. By integrating Blockchain technology into the AIM framework, the system has significantly enhanced data integrity, security, and traceability throughout the asset lifecycle. With a focus on practical application in the Saudi construction industry, rigorous evaluation by AM professionals ensured its alignment with industry needs and user expectations.

The system's architecture, designed following the OSI model, has established a robust and secure environment capable of managing complex asset data through a tiered structure that facilitates seamless information flow. From user registration to the final handover of immutable asset records, the architecture supports crucial processes such as verification, approval, and revision, essential in AM. The successful beta test within the KSA Makkah region, particularly at the Female Driving School at the KAAU, marks a significant milestone in digital AM and serves as a model for future construction projects.

In summary, this chapter highlights the transformative potential of integrating Blockchain into AIM, showcasing how such integration can revolutionise efficiency, transparency, and trust in operations. As we look ahead, this system stands as a testament to the tangible benefits of technological advancements, potentially reshaping the construction industry and offering a scalable model for global adoption once the technical challenges are overcome.

Chapter 5

Experiment

5.1 Introduction

This chapter emphasizes the essential role of technological integration in enhancing AM processes. It specifically explores the combined application of AIM and Blockchain technology to improve efficiency throughout the asset lifecycle, aligning with the industry's call for better performance, quality, and time management. Whereas Chapter 3 delineated the research methodology, Chapter 4 introduced a Blockchain-enabled environment that integrates BIM and AIM, and Chapter 5 went into analysing and validating the various impact factors on AM lifecycle operations using AIM and Blockchain. This validation is important, as it not only empirically supports the theoretical framework established earlier but also meets the third objective mentioned in Chapter 1.

This chapter offers a thorough analysis of impact factors across the different stages of the AM lifecycle (Design and construction stage; Handover stage and use stage) and provides recommendations, thereby supporting the effectiveness of employing AIM and Blockchain to improve AM lifecycle operations within the KSA. By examining these lifecycle stages and advocating for the integration of AIM and Blockchain, the research presents a systematic approach to addressing current inefficiencies in the AEC sector, aligning with the strategic goals of Saudi

Arabia's Vision 2030 [39].

This strategy aims at advancing AM practices by leveraging innovative technologies, thus contributing to the sector's progress. The validation of the impact factor analysis within this chapter furnishes valuable insights, underscoring the transformative potential of technological integration in revolutionising AM practices within the AEC sector.

5.2 Research Design and Methodology

The researcher employed a mixed-methods strategy, grounded in a pragmatic philosophy (as extensively discussed in Chapter 3) and utilised a deductive approach. A flowchart of the research process can be found in Figure 5.1. On this basis, a two stages approach was taken to collect qualitative and quantitative data using various data collection techniques within a dedicated time frame (2 months):

1. *Stage I aims to investigate and understand the current practice (qualitative data) through a workshop by conducting interviews and surveys with asset managers in the KSA to understand their current state-of-the-art AM practices.*

2. *Stage II aimed to address Ho, H1, and H2 through expert evaluations, focusing on the effects of integrating AIM and Blockchain technology on AM lifecycle operations in the KSA.*

5.3 Data Analysis

Stage I The initial workshop 2, detailed in Appendix C, conducted among professionals in the KSA, supports and contextualises the academic research's focus on AM. The research revealed a surprising lack of awareness about AM paradigms among industry practitioners, with more than 32 people of the workshop participants indicating that they were not familiar with the AM paradigm. This gap

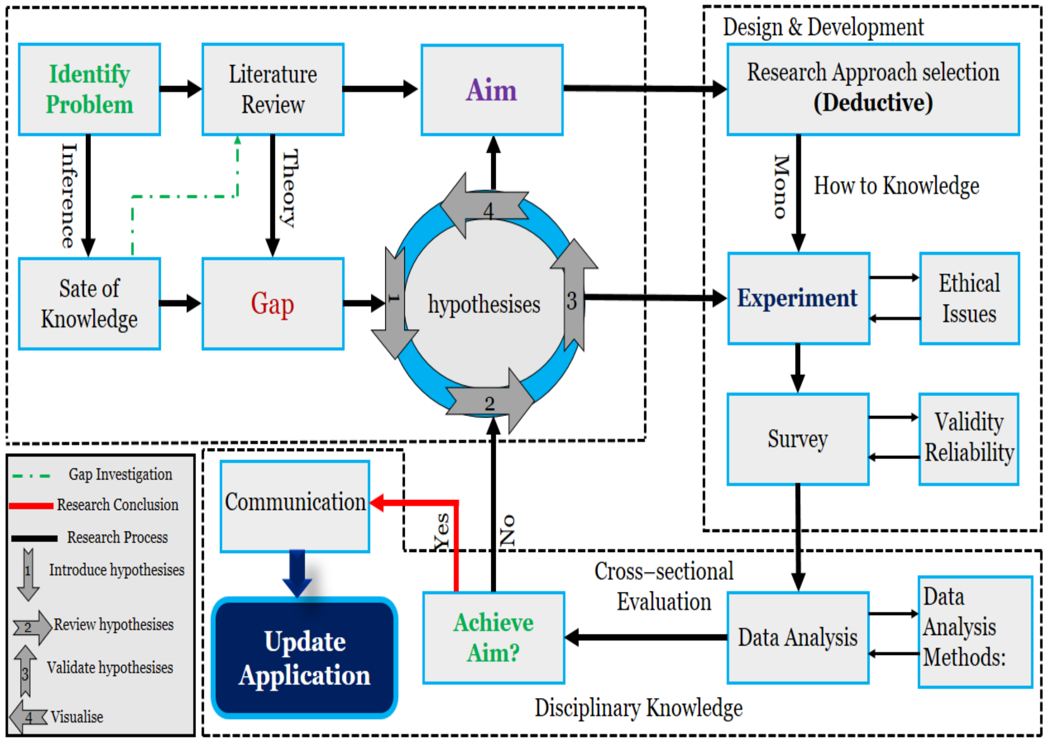

Figure 5.1: *Research processes*

in understanding and implementation increases the importance and relevance of the proposed framework integrating BIM, AIM, and Blockchain technology. The workshop participants pointed out the advantages and disadvantages of their current AM practices. Results can be found in Table 5.1. While benefits such as stakeholder equality, flexibility for change, and procedural familiarity with contractors and clients were noted, significant challenges were also highlighted. These challenges included poor communication, difficulty in making any changes during the asset lifecycle [20], lack of coordination, inconsistent approaches, language [80], insufficient data management [195], low return on investments and non-scheduled (ad hoc) decisions [195]. Each of these challenges corresponds with the gaps identified in the literature, providing empirical support for the research's proposed solutions.

Specifically, adopting the integrated framework could provide a standardised language and approach for AM, improving communication and coordination and procedures familiar to most contractors and clients [195]. Smart contracts can

Table 5.1: AM factors in different project management lifecycles

Impact factors of AIM in design and build	**Impact factors of AIM in handover stage**	**Impact factors of AIM in in-use performance**
Increase mutual trust, and recognition of new project roles, such as information manager	Commission plans	Health and safety
Inappropriate quality assurance methods and procedures	Building drawings and specifications	Reliability of equipment
Lack of transparency and accessibility of project data for all project team electronically	Insurance	Standard of operations
Not enough time for operations training	Manufacturer	Cost of operations
Responsibilities of various project team members are unclear	Product data	Cost of maintenance
Maintenance manuals and keys are often missing	Quality Control documents	Better planning
Ability to use the information across the design/build team	Operations and Maintenance manual	Information at every stage
The actual handover process is often an afterthought event	Equipment lists	Better use of resources
Minimise defects	Daily reports	Cost savings
Cost reduction	——	Time savings
Control construction process	——	Following international standards
Save time	——	Sustainability and Life cycle costing
Legislation and legal requirements Stakeholders influence	——	Management of energy consumption
——	——	Easy access to project data and information
——	——	Increase speed of preparing AMS
——	——	Better collaboration between stakeholders and ROI

automate various tasks, making the decision-making process more planned and efficient. Moreover, the secure data management enabled by blockchain technology can solve poor data management, one of the critical disadvantages noted in the KSA research. Thus, the workshop results validate the need for the comprehensive AM framework proposed in the literature and demonstrate its potential for practical, real-world application.

Stage II After stage I, the researcher used a case research approach, as has been recommended by [172], to meet Objective 3 (Chapter 1). On this basis, workshop II (in Appendix C) aimed to introduce AIM to the audience through an example, explaining what it is, why it's important, and how it can be used alongside blockchain technology to support the AM lifecycle (Design and construction stage; Hand over stage and In use stage). On this basis, the researcher developed a platform to demonstrate how blockchain and AIM could be integrated during the asset life cycle (detail was presented in Chapter 4). Following the demonstration, a survey employing statistics was conducted to evaluate the impact of AIM and Blockchain technology on AM lifecycle operations within the KSA. This involved analysing arithmetic mean, standard deviations, and frequencies, as well as utilizing logistic regression modeling, to confirm the research's findings.

To ensure reliability, Mean Value Analysis and the Chi-square Test were employed to assess the following statements regarding the impact of integrating AIM and Blockchain technology at different stages of the AM lifecycle. The specific impact statements under investigation are: The first statement explores the impact of applying AIM and Blockchain during the design and building stage of the AM lifecycle. The second statement evaluates their effect on the commissioning, operations, and maintenance stage of the AM lifecycle. The third statement assesses their influence on the in-use performance stage of the AM lifecycle.

For data validity, the Cronbach's Alpha test was applied. The size of the chosen sample was determined based on statistics from the General Authority of Statistics (2022) and the Saudi Council of Engineering (SCE), intending to obtain a representative sample size for reliable research validation. With SCE having 429,247 registered members, the research required a minimum of 96 responses from qualified engineers and IT professionals to achieve a 95% confidence level with a 10% margin of error. Participants were recruited after the SCE had advertised the research on its website, and the researcher had promoted the workshop through emails and social media platforms. The demographic breakdown of the received responses included 21.6% from owners, 40.5% from consultants, 27% from contractors, 5.4% from suppliers, and another 5.4% from the IT sector.

Moreover, 48.6% of the participants held a bachelor's degree or higher, indicating that the responses were informed by both professional experience and academic background. This diverse sample comprised construction industry project managers, with distribution across various levels of experience: 35.1% had 0-5 years, 27% had 5-10 years, 10.8% had 10-15 years, and the remaining 2% possessed over 15 years of experience. Despite a significant portion of the sample having less than 5 years of experience, their perspectives were valued, particularly since "lack of in-house expertise is one of the key barriers to BIM adoption" was recognised [93].

It was noted that 48.6% of participants had used BIM modeling software in the past year, which aligns with the National Report's findings that BIM usage has seen growth in the KSA, and 21.6% had used it within the last two years. Consequently, the influence of global BIM adoption on the KSA has been made evident, with an increasing preference among senior and executive members to utilise BIM not just as a paradigm shift but as a practical tool. Remarkably, project delivery using BIM files was reported to be implemented by 40.5% of the executives interviewed, a practice that was found at the senior level as well. Furthermore, it was revealed that for 54.1% of large-scale projects, the importance of project handover with BIM files remains critical. This sentiment was echoed by 24.3% of respondents who deemed it "Important," thereby emphasising the project handover stage's significance to both the organisation and its clients, as viewed within the research sample. The variable questions of the survey were based on a Likert scale, with responses ranging from "Very Important" to "Not Important" (where Very Important = 1, Important = 2, Slightly Important = 3, Least Important = 4, and Not Important = 5), allowing for a quantitative assessment of each response's importance. The **sub-questions** are: *Impact of Integrating AIM and Blockchain in the Design and Build Stages of AM Lifecycle.* Within the construction sector, it is standard practice to distribute tasks across specialised subcontractors, each approved by a consultant advisor, a fact supported by references [147] and [102]. Thus, drawing from this research insights, Table 5.1 offers a comprehensive examination of this pattern, specifically focusing on the "Impact of Integrating AIM and Blockchain in the Design and Build Stages of the AM Lifecycle."

This research explores the impacts of integrating AIM and Blockchain technology within the AM lifecycle, particularly focusing on the design and construction stages. Survey data, as reflected in Table 5.2, provides a quantitative foundation for understanding the perceived benefits and areas for enhancement from the industry professionals' perspective. Notably, the highest rated benefits, such as the influence on stakeholders and the enhancement of trust and recognition of new project roles, underscore the potential of these technologies to significantly improve stakeholder engagement and project transparency [93]. Additionally, the recognition of economic and efficiency benefits, such as cost reduction and time savings, highlights the practical advantages perceived by the industry. However, the research also identifies critical areas requiring focused improvement, notably in enhancing information sharing across design and construction teams and offering targeted online training to operations team members. The moderate level of consensus among respondents, as indicated by the standard deviations, suggests a general agreement on these technologies' potential impacts, albeit with room for further exploration and validation.

Overall, this research contributes to the burgeoning body of knowledge on digital transformation in construction, offering empirical insights into the practical implications of adopting AIM and Blockchain technologies in enhancing AM processes [150]. Furthermore, Figure 5.2 displays the relationship between mean value and

Table 5.2: analysis for sub-questions

NO	**Question**	**Mean**	**STD. Deviation**
1	Improve trust, and recognise new project roles	2.62	1.34
2	Improve AM quality assurance methods and procedures	2.24	1.12
3	Increase the level of transparency through accurate project data accessibility	2.19	1.20
4	Offer online training to operations team members	2.16	1.40
5	Provide clarity to responsibilities in various project team members	2.32	1.25
6	Assets' manuals to be available and accessible alongside their information models	2.19	1.24
7	Share assets' information across the design/ construction team	2.03	1.32
8	Improving the construction to handover process automatically	2.30	1.24
9	Minimise defects	2.35	1.32
10	Cost reduction	2.54	1.32
11	Control construction process	2.32	1.38
12	Save time	2.51	1.50
13	Clarifying legislation and legal requirements	2.38	1.36
14	Stakeholders influence	2.68	1.43
Design and Construction stage		2.36	1.06

standard deviation. Regression analysis reveals a relationship ($R^2 = 0.2549$) between the Mean and SD. A notable result is that the ability to use information through out the design and build stage has a mean of 2.46. This underscores the significance of these stages in AM. Conversely, the data indicates a barrier in the form of inadequate time for operations training. Yet, 46% of respondents recognise the importance of utilising information during these stages, while 40.5% view the lack of training time as a significant challenge. These results show the importance of efficient information management. Still, there remain challenges to extend this efficiency beyond the design and build stages [196]. As per the results, maintenance manuals and keys are frequently overlooked, scoring lower in importance [22].

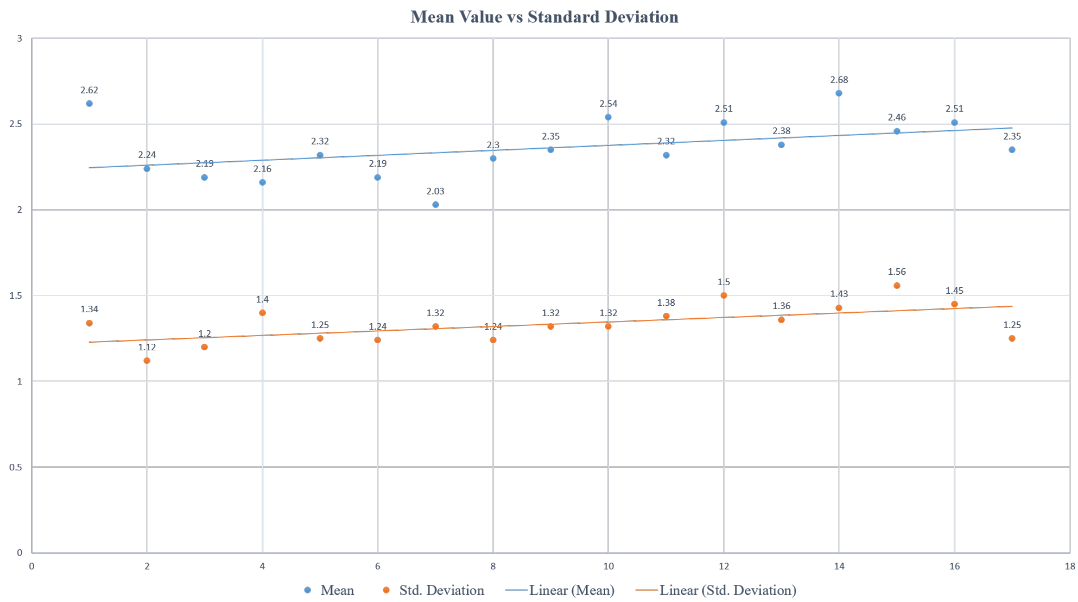

Figure 5.2: *Mean Value VS Standard Deviation.*

In addition, conducting regression analysis shows that the relationship between Mean and SD is $R^2 = 0.2549$. Figure 5.3 illustrates a linear equation of standard deviation for the design and construction stage. The Chi-square Hypotheses Test, conducted to assess the significance of a model evaluating the efficiency of integrating AIM and Blockchain in the design and construction stages, yielded a Chi-square value of 8.929 with a significance level under 0.05 (p=0.012). This outcome significantly supports the model's aptness in measuring the integration's effectiveness. The incorporation of the 'design and build' variable not only improved the model's quality but also illuminated the specific impacts of this technological integration. Utilised key metrics, including Cox-Snell R2 and R2 Nagelkerke [197], quantified the variance in the efficiency of AIM and manage-

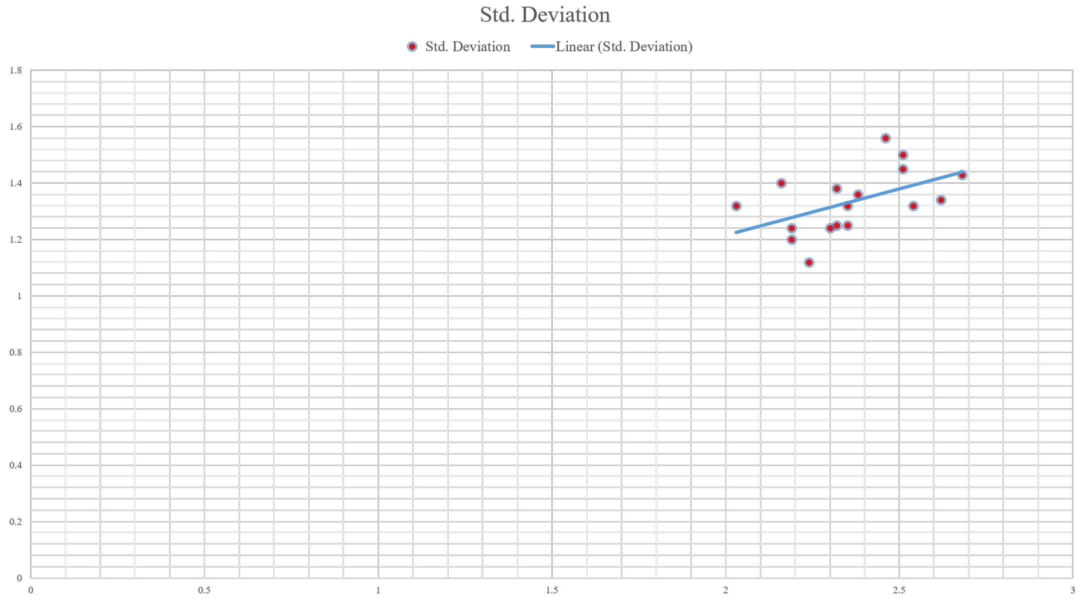

Figure 5.3: *Linear equation of Standard Deviation.*

ment attributable to design and construction processes. These metrics indicated that the integration could explain between 15.8% and 23% of the efficiency variations, showcasing a substantial impact. Additionally, the regression coefficient for the 'design and build' variable was found to be B = 1.098, indicating a notable positive effect on the efficiency variable. The Wald value of 4.590 further confirmed the significant influence of the design and construction stages on AIM efficiency when integrated with BIM and Blockchain [198].

These findings underscore the statistical importance of integrating AIM and Blockchain in the initial phases of AM, highlighting measurable improvements in model quality and efficiency. By demonstrating the contribution of design and construction processes to the efficiency of AIM, this research adds valuable empirical evidence to the discourse on strategic technology adoption in AM, enriching the existing literature. The results advocate for further investigation and substantiation, indicating a promising area for future research in the sector. For detailed analysis and discussion on the integration of AIM and Blockchain in design and construction and its impact on AM efficiency, readers and the researcher is directed to reference [198]. In summary, the data on factors affecting

AM's design and build stage by using AIM and blockchain technology reveals a consistent theme of moderate to low satisfaction across various dimensions, with mean scores ranging from 2.03 to 2.62 on a scale of 1 to 5. This suggests an overarching need for improvements in nearly all facets of the process. Particularly concerning is the low score of 2.03 for 'Share assets' information across the design/construction team, which highlights a pressing need to enhance information sharing and collaboration.

Variability in the asset data, as indicated by $1.12 < SD < 1.50$ further suggests that experiences and perceptions are not consistent, indicating potential inconsistencies in process implementation or training. Building on these insights, it's essential to emphasise the standardisation of procedures to decrease variability and to concentrate on phases such as information sharing. This approach is aimed at enhancing overall efficiency and satisfaction, which in turn could positively influence the handover process. Consequently, H0—that operating AIM and Blockchain in the design and build stage of the AM lifecycle has an impact—cannot be unequivocally accepted, there is compelling evidence to suggest a potential positive effect.

5.3.0.1 H1: Impact of AIM and Blockchain in the Commissioning, Operations, and Maintenance Stages of the AM Life Cycle

The survey data, delineating the accessibility of critical information during the Commissioning, Operations, and Maintenance Stages of the AM lifecycle, reveal insights into the current state of information dissemination within this domain. With mean values ranging from 2.03 to 2.68, the findings suggest a moderate level of accessibility to key documents and data, pinpointing both strengths and areas ripe for enhancement. Notably, the accessibility of products' data emerges as a relative strength (mean: 2.68, SD: 1.20), suggesting that stakeholders find it relatively easier to access product-specific information. Conversely, the accessibility to equipment lists and product warranties, with mean of 2.03 and 2.05

respectively, highlights discernible gaps in the availability of essential information, underscoring a crucial area for improvement. The overall moderate accessibility score (mean: 2.23, SD: 0.96) for the Commissioning, Operations, and Maintenance Stage further substantiates the need for targeted interventions aimed at standardizing access to vital information. The consistency in standard deviations across the responses indicates a consensus among participants, although it also points to varying degrees of satisfaction with information accessibility. This data not only enriches our understanding of the current landscape of information management within AM but also signals clear directives for advancing practices to bolster efficiency, effectiveness, and stakeholder satisfaction in the sector [64]. In Figure 5.4, the regression analysis shows a relationship ($R^2 = 0.311$) between

Table 5.3: Analysis table for Commissioning, Operations, and Maintenance Stage

NO	**Question**	**Mean**	**STD. Deviation**
1	Access to commission plans	2.22	1.42
2	Access to building drawings and specification	2.19	1.29
3	Access to Products' Warranty	2.05	1.10
4	Access to manufacturer details	2.35	1.38
5	Access to products' data	2.68	1.20
6	Access to quality control documents	2.11	1.07
7	Access to operations and maintenance manual	2.16	1.12
8	Access to equipment lists	2.03	1.09
9	Daily reports	2.32	1.20
Hand over stage		2.23	0.96

Mean and SD. Notably, statistics revealed a mean of 2.32, while real-time manufacturer data was identified as a challenge with a mean of 2.35. With 43% of respondents noting the significance and 40.5% emphasising the importance of commission plans, building drawings, specifications, and operation/maintenance manuals, these factors influence AM performance. However, despite the perceived advantages, there are still challenges to be addressed, especially concerning the use of data beyond the commissioning, operations, and maintenance stages. Most significant was the equipment lists' question, with a mean score of 2.03, while access to product data scored the lowest. These findings highlight the importance of optimising the use of AIM and Blockchain throughout all stages. Based on the responses from the interviewees and the following descriptive statistics analysis Awareness of techniques used and the strengths and limitations will illustrate the analysis for the above sub-questions in Table 5.3.

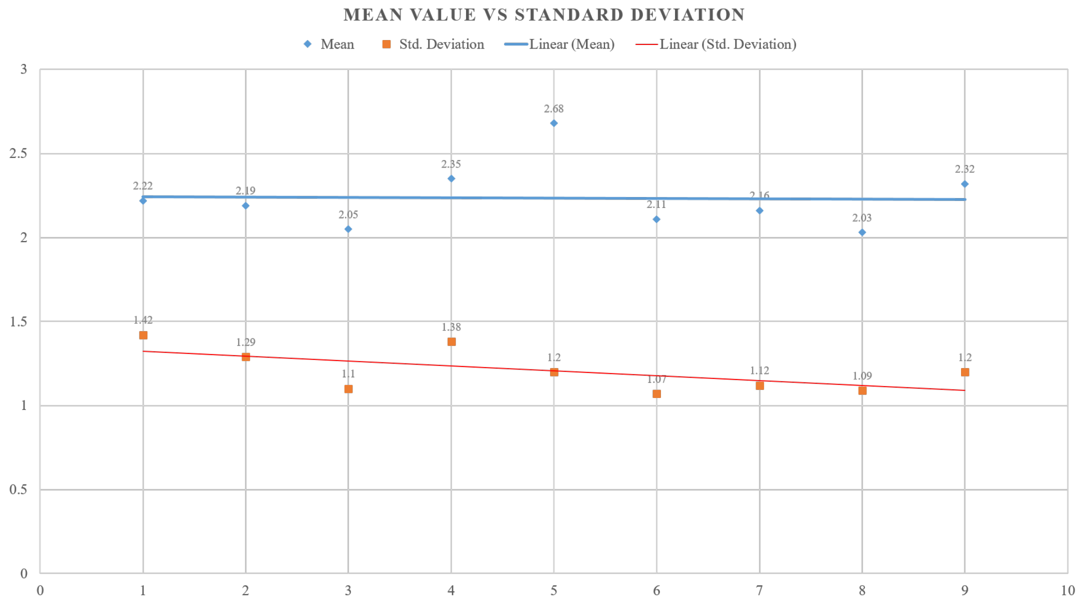

Figure 5.4: *Mean Value VS Standard Deviation Handover stages.*

Chi-square Hypotheses Test:

The statistical analysis examining the impact of the Commissioning, Operations, and Maintenance stage on AIM efficiency produced a significant Chi-square statistic ($X^2 = 8.249$) with a p-value of 0.003, highlighting the substantial role in the handover stage in AIM's effectiveness. When the handover stage was introduced as an independent variable, it was shown to explain 21.4% and 31.1% of the variance in AIM efficiency, as indicated by Cox-Snell R^2 and R^2Nagelkerke, respectively. This suggests that the handover stage substantially contributed to the efficiency of AIM, a conclusion further supported by a significant coefficient (B= 2.045) for the commissioning, operations, and maintenance phase, indicating a considerable increase in efficiency. These findings affirm the critical nature of thorough documentation and models in enhancing AIM, consistent with earlier studies [30]. Despite the data demonstrating the beneficial impacts of AIM and Blockchain on the AM lifecycle, particularly during the handover stage, it also reveals areas for potential improvement.

Optimisation across different phases and data points could further elevate efficiency and effectiveness. Although initial analyses showed moderate to low satisfaction levels with the impact of AIM and Blockchain integration, the effect of the commissioning, operations, and maintenance stage on AM lifecycle efficiency raises a pertinent question: Could enhancements in these stages lead to more effective use and impact of AIM and Blockchain technologies? The statistical findings suggest that focusing on the commissioning, operations, and maintenance stages could be a key area for boosting the overall impact of AIM and Blockchain within the AM lifecycle. This analysis not only deepens the initial critique but also identifies the commissioning, operations, and maintenance stages as crucial elements in optimising AIM efficiency. Thus, enhancing these stages emerges as a promising strategy to elaborate the benefits of AIM and Blockchain in AM.

5.3.0.2 H2: Impact of AIM and Blockchain on AM During the In-Use Stage.

An analysis was conducted to discern the impact of AIM and Blockchain technology on AM during the In-Use Stage. Survey respondents provided feedback that was quantitatively measured, with mean scores spanning from 1.89 to 2.32 and $1.01 < SD < 1.27$ ranging from 1.01 to 1.27. This data indicated a moderate to high consensus on the effectiveness of integrating AIM and Blockchain within AM processes, particularly during the operational life of assets. The highest mean score, 1.89, associated with improvements in health and safety, underscored AIM's critical role in bolstering safety measures through enhanced asset information richness. Additionally, AIM and Blockchain were found to significantly boost equipment reliability and AM operational standards, with mean of 2.00 and 2.19 respectively, highlighting their importance in sustaining asset integrity and performance. The analysis also revealed substantial cost savings in operations and maintenance, attributed to precise AIM accessibility, suggesting a role for these technologies in financial optimisation during the asset's use phase. Moreover, the capacity of AIM to facilitate strategic planning and resource management emerged as a benefit, enhancing overall AM efficiency. Notably, the survey underscored AIM's contribution to compliance with international standards and promotion of sustainability, pointing to its utility in supporting environmentally conscious AM practices.

The influence of AIM on lifecycle cost reduction and energy consumption optimisation further highlighted its potential to improve the economic and environmental sustainability of assets. Hence, based on the findings the integration of AIM and Blockchain considerably enhances AM practices during the In-Use Stage, leading to improvements in safety, reliability, cost efficiency, and sustainability, thereby affirming their indispensable role in optimising the operational lifecycle of assets. Mean Value Factor Analysis Through detailed scatter analysis, a discernible relationship between the collected datasets was unveiled, with regression analysis further elucidating this connection by indicating an R^2 value of 0.290.

This value points to a moderate relationship between the mean scores and standard deviations of the various aspects assessed, signifying a certain level of predictability and correlation within the data.

Particularly noteworthy was the finding regarding health and safety, which registered the lowest mean value (1.89), as presented in Figure 5.5, highlighting it as a critical area of concern and priority among respondents. In stark contrast, the challenges associated with standardising operations (mean: 2.19) and accelerating the preparation of AMS (mean: 2.30) were identified as significant hurdles, complicating the post-handover utilisation of information. Remarkably,

Table 5.4: Analysis table for the in-use stage.

NO	Question	Mean	STD. Deviation
1	Improve Health and safety due to asset information richness	1.89	1.26
2	Increase the degree of equipment's reliability due to the visualisation of them	2.00	1.03
3	Improving AM standards of operations through AIM	2.19	1.10
4	Reducing cost of operations due to accurate AIM accessibility	2.08	1.16
5	Reducing cost of maintenance due to accurate AIM accessibility	1.97	1.21
6	Better planning due to accurate AIM accessibility	2.24	1.12
7	Proving continues and updated AIM at every stage within the project management lifecycle	2.05	1.25
8	AIM accessibility allows asset managers to better use of their resources	2.22	1.06
9	Reducing CAPex and OPex Costs due to accurate asset information accessibility	2.32	1.16
10	Improve delivery time due to accurate asset information accessibility	2.08	1.19
11	Following international standards	2.00	1.15
12	Sustainability due to the capacity in an AIM to visualise how environmentally friendly each equipment/material is and test it virtually by reducing significant risks	2.16	1.14
13	Reducing Life cycle costing due to accurate asset information accessibility	2.03	1.14
14	Optimising Management of energy consumption due to virtual simulation of AIM in a BIM model.	2.22	1.27
15	Easy access to project data and information	2.05	1.13
16	Improve AM process	2.19	1.10
17	Increase speed of designing integrated AMS	2.30	1.10
18	Improve collaboration between stakeholders due to accurate asset information accessibility	2.30	1.24
19	Instant access to Asset AIMs enables shareholder(s) to review and increase the predictability of the ROI by being more accurate.	2.32	1.20
In use stage		2.14	1.01

with 60% of the responses emphasising the paramount importance of health and safety, it becomes evident that, despite the recognition of its benefits, substantial challenges persist in effectively leveraging asset information post-handover. This is particularly true within the In-Use Stage, where the responses underscored health and safety as a primary concern, evidenced by its lowest mean score. On the other end of the spectrum, aspects such as cost savings and ROI, both scoring a mean of 2.32, were deemed of lesser importance by the respondents. This distribution of priorities and perceived challenges suggests a complex landscape where the benefits of AIM and Blockchain in enhancing AM practices, especially regarding health and safety during the asset's operational life, are acknowledged but also accompanied by significant hurdles in standard operations and efficiency gains. Thus, the analysis not only reflects the critical areas of focus for improving AM practices through AIM and Blockchain integration but also highlights the nuanced challenges that need to be addressed to fully harness these technologies' potential benefits. The graphical representation of the comprehensive

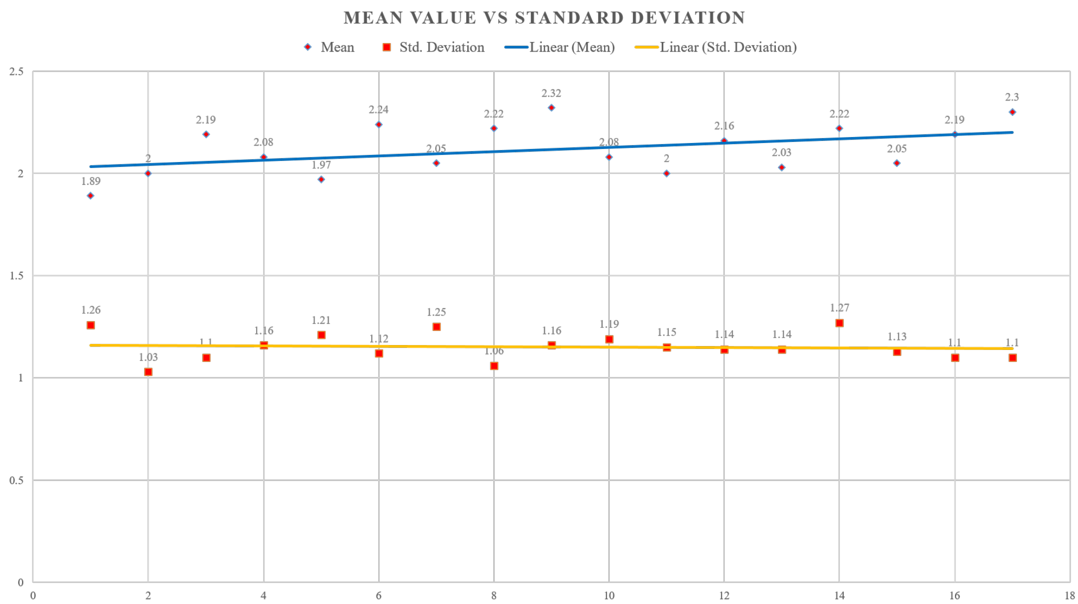

Figure 5.5: *Mean Value VS Standard Deviation In use AM stage.*

mean value for the Hypothesis through the Chi-square test shows a Chi-square statistic of 8.249, with a significance level below the threshold of 0.05, specifically at 0.004. This statistical evidence validates the model's significance and the accuracy of data representation. Following the introduction of the independent variable representing the In-Use stage, the R^2 values, according to Cox Snell and Nagelkerke, suggest that fluctuations during the In-Use stage contribute to 20% to 29% of the variance in the efficiency of AIM and Blockchain. Furthermore, the model's regression coefficient for the In-Use stage is recorded at 1.889, indicating a proportional increase in efficiency by a factor of 1.889 concerning the logarithm of the dependent variable's optimal value. The significance of the In-Use stage is further underscored by a Wald statistic of 3.988 and a significance level below 0.05 (specifically, 0.046), highlighting its considerable influence on the efficacy of AIM and Blockchain integration. This finding suggests the potential for stakeholders to better protect commercial data and intellectual property rights through the strategic application of these technologies.

The $1.01 < SD < 1.27$, presents a moderate variability in the responses, indicating diverse perceptions among the respondents. At its core, H2 posits that the In-Use stage of the AM lifecycle has substantial repercussions for the efficiency of AIM and Blockchain, noting clear advantages in areas like health and safety but also pinpointing challenges in achieving operational standards and expediting the preparation of AMS. Addressing these challenges through targeted improvements could significantly enhance the effectiveness of AIM and Blockchain.

Descriptive statistical analysis, incorporating responses and awareness of techniques, along with understanding their strengths and limitations, furnishes a detailed examination of Hypothesis 2, as illustrated in Table 5.4. The statistical review elucidates the intricate effects of employing AIM and Blockchain during the AM 'In Use' phase. On one side, the enhancement of health and safety through AIM is acknowledged as crucial by 60% of participants. On the flip side, the elevated mean scores for operational standards and AMS preparation speed (2.19 and 2.30, respectively) spotlight the existing obstacles that hinder the full utilisation of AIM in AM. Statistically, the 'In Use' stage accounts for a significant portion of the variance in AIM's effectiveness, underlining its importance while also hinting at the presence of other influential factors.

Validity

To ensure the consistency of the questionnaire (Appendix B), the researcher utilised Cronbach's Alpha test [177], This measure determines the reliability of the research. As per Tavakol and Dennick [199] Cronbach's Alpha values range between 0 and 1, with values closer to 1.0 suggesting high internal consistency. A score of 1.0 would mean no measurement error. In contrast, a Cronbach's alpha value of 0.70 or above is often deemed acceptable [200]. The findings are in Table 5.5. align with the PAS 1192-5:2015 standards, emphasising the benefits of new technology and AIM for stakeholders. With a sample size of 37, the Cronbach's Alpha test confirmed the results' reliability, indicating a 2.8% error. Table 5.6 provides averages across all project delivery stages. As per the table, every stage received a degree of importance based on the Likert scale. By employing

Table 5.5: Chi test for the Model Coefficients and Model Summary

Item	**Chi-square**	**df**	**Sig.**	**B**	**Wald**	**Sig.**	**Exp(B)**	**Cox and Snell R2**	**Nagelkerke R2**
H0	6.376	1	0.012	1.098	4.590	0.032	2.998	0.158	0.230
H1	8.929	1	0.03	2.045	4.079	0.043	7.730	0.214	0.311
H2	8.249	1	0.004	1.889	3.988	0.046	6.613	0.200	0.290

key statistical measures such as Chi-square values, significance levels (Sig.), and regression coefficients Exp(B), a meticulous assessment has been undertaken. Notably, H1 emerges as important, evidenced by its highest Chi-square value (8.929) and substantial regression coefficient (Exp(B) = 7.73), underscoring a robust association and considerable impact within the variables under research. Following closely, H2 demonstrates notable significance, supported by a compelling Chi-square value (8.249) and a substantial regression coefficient (Exp(B) = 6.613), indicating its substantive contribution to the research framework.

Conversely, while H0 presents a moderate Chi-square value (6.376) and a relatively lower regression coefficient (Exp(B) = 2.998), its significance level (Sig. = 0.012) warrants attention, albeit to a lesser extent compared to H1 and H2. This comprehensive analysis offers a clear hierarchy of importance among the hypotheses, providing valuable insights for further exploration and theoretical development within the research domain.

Table 5.6: Data Validity

Factor	**Cronbach's Alpha**	**Mean**	**STD. Deviation**
Design and construction stage	0.963	2.36	1.06
Hand over stage	0.924	2.23	1.06
In use stage	0.982	2.14	1.06

This section of the research presents the assessment of three distinct factors representing stages within a process or project, denoted as H0, H1, and H2. Utilizing Cronbach's Alpha, a measure of internal consistency, each stage is evaluated for its reliability. The results reveal commendable levels of internal consistency across all stages, with H2 displaying the highest reliability (Cronbach's Alpha = 0.982), followed by H0 (Cronbach's Alpha = 0.963) and H1 (Cronbach's Alpha = 0.924). Additionally, mean scores elucidate the central tendency of responses or observations for each factor, with H0, H1, and H2 exhibiting mean scores of 2.36, 2.23, and 2.14, respectively. Furthermore, the consistent standard deviation of 1.06 across all stages indicates uniform variability in the scores. These findings underscore the robustness and reliability of the measurements, providing a solid foundation for subsequent analyses and interpretations within the research.

5.3.1 Asset Data and AM Efficiency Through AIM and Blockchain Technology

In the AM, the integrity, accessibility, and utility of asset data stand as critical pillars that underpin the effective lifecycle management of assets. This section delves into the transformative role of AIM and Blockchain technology in elevating asset data management practices as per participants' survey responses. By examining the compliance with "Optional" and "Conditional" data categories as delineated in Tables 5.7, 5.8, and 5.9, it was explored how these cutting-edge technologies can significantly bolster data integrity, operational efficiency, and strategic foresight in AM.

Table 5.7: Extent of compliance with the building details data in the operation stage

Building details	**Optional**	**Conditional**
Area/ Volume	10	27
Design Criteria	11	26
Spare Part Information	12	25
Manufacturer/ Vendor Info	7	30
Asset Location	9	28
Building Use Type	6	31
Year Of Built/ Renovation	11	26
Address	10	27
Owner	12	25
Type Of HVAC System	8	29
Installation Guide	11	26
Expected Life	9	28
Maintenance History	10	27
Inspection Report	8	29
Key Plans	15	22
Asset Name	15	22
Equipment Lists	14	23
Asset Description	18	19
Identification Number	15	22
Spatial Information	15	22
Installation Date	13	25
Asset Specification	14	23
O And M Manuals	16	21
Classification	15	22
Asset Condition	15	22
Accessibility Performance	15	22
GIS Coordinates	14	23
Locations Of The Valves	15	22

In terms of energy buildings compliance, the energy data of assets are required to be listed below in Table 5.8:

Table 5.8: Extent of compliance with the building details data in the operation stage

Energy data	**Optional**	**Conditional**
Energy consumption heating	15	22
Energy consumption electricity	14	23
Energy consumption cooling	13	24
Water consumption	10	27
Locations of the control panels	8	29

In terms of the extent of compliance with the long-term planning data in the Operation stage in Table 5.9:

Table 5.9: Extent of Compliance with the Long-term Planning Data in the Operation Stage

Long term planning	**Optional**	**Conditional**
Planned maintenance costs all types	10	27
Planned maintenance costs all types- sub tasks	11	26
Facility general information	11	26
Type of data required	9	28

Based on the data received from the interviews, here's how these technologies can enhance AM, leveraging the data compliance categories mentioned:

AIM:

1. Data Structuring and Accessibility: AIM can structure and enhance the accessibility of both (Optional) and (Conditional) data by creating a unified model that integrates various data types—from spatial information and energy consumption to long-term planning and maintenance history. This can improve decision-making and operational efficiency.

2. Predictive Analytics: For the conditional data related to energy consumption and long-term planning costs, AIM can employ predictive analytics to forecast future consumption patterns, maintenance needs, and planning costs. This can lead to more effective resource allocation and cost savings.

3. Lifecycle Management: AIM supports lifecycle management of assets by ensuring that all relevant data, such as installation date, expected life, asset condition, and maintenance history, are accurately recorded and easily accessible. This facilitates proactive management and extends the lifespan of assets.

Blockchain Technology:

1. Data Integrity and Security: Blockchain can ensure the integrity and security of the recorded data by creating an immutable ledger of transactions. This is particularly relevant for conditional data that require rigorous documentation and verification processes, such as inspection reports, maintenance history, and asset specifications.

2. Smart Contracts for Conditional Compliance: Smart contracts can automate compliance with conditional requirements by executing predefined actions when certain conditions are met, such as scheduling maintenance or updating energy consumption records. This reduces the administrative burden and ensures compliance with operational standards.

3. Decentralised Data Management: By decentralising data management, blockchain allows for a transparent, tamper-proof system where all stakeholders can access up-to-date, accurate information about the building assets. This is crucial for managing building details, energy data, and long-term planning data efficiently and effectively.

4. Enhanced Collaboration and Trust: Blockchain facilitates improved collaboration and trust among various stakeholders, including owners, operators, and maintenance teams, by providing a single source of truth for all asset-related data. This is especially important for ensuring compliance with both optional and conditional data requirements.

By integrating AIM and Blockchain technology, the impact of various factors on AM can be more accurately assessed and optimised. For instance:

- Efficiency and Sustainability: The use of predictive analytics (through AIM) and real-time data management (enhanced by Blockchain) can significantly impact energy efficiency and sustainability efforts, directly linking to the compliance data for energy consumption.
- Cost Management: The ability to forecast and plan for maintenance costs, utilizing both optional and conditional data, can have a profound impact on the overall cost management and financial planning for assets.
- Regulatory Compliance and Risk Management: Ensuring data integrity and security, along with automated compliance checks through smart contracts, can mitigate risks associated with regulatory non-compliance, fraud, and data breaches.

In essence, integrating AIM and Blockchain technology in managing the compliance data outlined in Tables 5.7, 5.8, and 5.9 can enhance the effectiveness, efficiency, and reliability of AM processes. This integration not only ensures compliance but also optimises operational performance and strategic planning, ultimately contributing to the long-term sustainability and resilience of building assets. In addition integrating the insights from the previous sections with the detailed applications of Blockchain and AIM across different phases of the AM lifecycle—Design and Build Phase, Commissioning, Operations, and Maintenance Stage, and In-Use Performance Stage—yields a comprehensive view of enhancing asset data and AM efficiency. The collective examination underlines the symbiotic relationship between technological advancements and AM practices, encapsulated in a collective table format for clarity and strategic insight Table 5.10.

In synthesising the research's findings, it becomes evident that the integration of Blockchain technology represents a pivotal advancement in the management of building operations, extending its influence beyond traditional practices. This integration, particularly within the domain of construction management as explored by [201], unlocks significant potential for enhancing information manage-

Table 5.10: Code Snippet Interpretation Table

AM Lifecycle Phase	**Technology Utilization**	**Benefits and Enhancements**
Design and Build Phase	Blockchain for mutual trust and transparency. AIM for integrating RFID with maintenance manuals and keys.	• Improved clarity in team responsibilities through quality assurance and operational training. • Streamlined access to information, reducing defects and costs. • Enhanced legal compliance and quality control.
Commissioning, Operations, and Maintenance Stage	Blockchain for securing commission plans, building drawings, insurance data, and quality control documents.	• Immutable record keeping ensuring smoother handover processes. • Time-saving in operational AM due to secure management of manufacturer's data and daily reports.
In-use Performance Stage	Blockchain for health and safety enhancements, equipment reliability, and adherence to international standards.	• Cost-effective operations and maintenance. • Improved planning and resource utilisation. • Enhanced sustainability efforts and lifecycle costing. • Energy management and stakeholder collaboration leading to ROI.

ment through the precise control and authentication of information exchanges at critical BIM server interfaces. Such an evolution in data handling introduces a paradigm shift toward more efficient compliance behaviors, prioritising operational needs, and leveraging the scalability of Blockchain technology to meet the demands of modern construction management practices. The immutable ledger system of Blockchain, a core focus of this research, redefines the landscape of data-sharing practices within building operations management, offering unprecedented levels of operational efficiency [201]. The reliability and standardisation of data facilitated by this technology address long-standing challenges within the sector. Yet, this advancement necessitates a high degree of precision in data entry, reflecting the unalterable nature of Blockchain records—a factor that demands careful consideration given its profound implications for AM. The research further highlights that Blockchain's impact transcends technical boundaries, extending to financial and educational dimensions. This underscores the necessity for comprehensive user training and adaptation strategies, emphasising that the successful integration of Blockchain into AM requires a multifaceted approach that encompasses technical, financial, and human capital considerations.

Empirical evidence, notably from [202], reinforces Blockchain's instrumental role in optimising AM across various lifecycle stages. This technology facilitates improved data management and operational efficiency and enhances collaboration and efficiency in AM practices, as seen in contexts such as the KSA. The findings illustrate Blockchain's capacity to streamline construction contract management, effectively managing information flows, payments, and supply chain logistics [202], and to address operational priorities, including the management of construction disputes [201]. However, the research cautions against an uncritical embrace of Blockchain's capabilities. The indispensable need for precision in data entry, coupled with considerations of scalability, infrastructure, and cost [136], [203], necessitates a balanced approach. These considerations are crucial for managing the extensive data involved in asset and building operations management, highlighting the complexity of deploying Blockchain technology in this domain. In conclusion, the integration of Blockchain technology into building operations management heralds a significant shift towards more reliable, efficient, and scalable AM practices. This shift, while promising, requires a comprehensive and nuanced understanding of Blockchain's capabilities, limitations, and implications across technical, financial, and operational dimensions. The research advocates for a balanced integration of Blockchain, informed by empirical evidence and aligned with theoretical frameworks, to fully realise its potential in enhancing AM efficiency and effectiveness.

5.3.2 Findings Discussion

The findings show that there are factors affecting the operation of AIM throughout the AM lifecycle by integrating blockchain. During the design and build, the research found that problems such as maintenance and key locations (m =2.68) could be easier to identify because of the use of technologies such as RFID, where data can be collected and saved within a chain of a block. Further, trust and a better understanding of project team members roles can be better clarified, while m =2.62. In addition, factors such as saving time (m =2.51), better control of the construction/maintenance processes (m =2.32), and cost reduction (m =2.51) are significantly impacted by the integration of blockchain and AIM in a way to improve operations and maintenance. It is noted that ISO55000 states that these factors are heavily affected if its standard is not applicable [204]. However, accessibility to information within a secure environment by the stakeholders could work as a driver to influence (m =2.35) project progress.

After conducting a Chi test exercise, the researcher checks the hypothesis to see how likely it is that the observed frequencies are true. Results show a significant input x2 =6.36, aiming to show the relevance of the input of blockchain and AIM throughout the design and construction life cycle. That complies with the idea of the BIM paradigm as per Eastman et al., [205] introduce as well as what ISO-19650 brings in terms of the need to evolve more technologies to offer more accurate and detailed AIMs. The impact of operating AIMs during commissioning, operations, and maintenance of the AM life cycle stage shows that the (suppliers') products' accurate data, where =2.68, could significantly impact. That happens because a detailed AIM, according to ISO-19650, requires a high level of detail that will allow, during the operational stage, the asset manager to pay more attention when and as problems arise. So, it is the first time we have observed the integrated use of ISO-19650 and ISO55000 in complementary work. On this basis, there is significant importance placed on whether the manufacturer is ready (m =2.35) to provide such detailed and accurate data and thus daily reports (m =2.32) to provide punctual results as is required by ISO-27001 and ISO5501:2014. The Researcher to ensure the hypothesis of how likely the observed frequencies would be assumed is true, then a Chi test exercise run.

The Chi test results x2 =8.929 show a significant input aiming to show the relevance of the input of blockchain and AIM throughout the handover process that is much higher compared to aim and design. That means there is more pressure to provide accurate and detailed data to AIM where, over a blockchain network, its transformation and retrieval can happen on time. This is a requirement for digital twins and the future of digital construction [206]. Finally, the impact of operating AIMs during in-use operations shows that the increased speed of preparing holistic and integrated AMS with value m =2.30 alongside the benefits of better collaboration between stakeholders with value m =2.30 could add value to better management of assets. Both are the main drivers for the integration of AIM and blockchain.

However, in the prime position to understand better the impact of AIM integration with blockchain technologies is the ROI it could bring to investors (m =2.32) because of continued input and processing of accurate data at any time during the operation process of an asset [85]. As a result, besides the cost savings, where m =2.32, assets' data could be better used because of the live stream of accurate data at any time. The Researcher to ensure the hypothesis of how likely the observed frequencies would be assumed is true, then a Chi test exercise run. The Chi test results show slightly higher results compared to handover 8.249, which clearly shows that the impact is heading more toward asset operations rather than design and construction. The last two, though, are good indicators showing how the integration could add value at earlier stages; however, by looking at Figure 5.5, it can be seen that the benefits are achieved mainly at the operational stage. For this assumption to be confirmed, Cronbach's alpha test was run, where results showed that the integration of AIM and blockchain technology works better in the operational stage (a =0.982; Table 5.6). Hence, based on the above, the utilisation of the design and build procurement method is highly recommended in a comprehensive project delivery, in which the overall responsibility is taken up by the general contractor [207]. Furthermore, the BIM execution plan will improve project outcomes, inform decision-making, and accelerate project delivery, as required by [62].

5.4 Summary

Chapter 5 elucidates the significant benefits derived from integrating Blockchain and AIM within the AM lifecycle, focusing on operational efficiency improvements as outlined in RQ3 (Chapter 1). This integration not only propels AM processes forward but also ensures alignment with international standards such as ISO-27001, ISO55001:2014 [36], and ISO-19650 [2], highlighting a comprehensive approach to enhancing data integrity, stakeholder collaboration, and operational efficiency. The integration of Blockchain and AIM technologies showcases profound impacts during the AM lifecycle's 'In Use' phase. Blockchain's immutable ledger is pivotal for meeting ISO-27001's demands for data security, creating a transparent and efficient data management system critical for ISO-55001:2014 [36] compliance, which focuses on AM systems. Simultaneously, AIM's capacity to provide accessible and structured asset data supports ISO-19650's requirements for the organisation and digitisation of information, including BIM, enhancing decision-making and operational efficiency.

This technological integration significantly improves safety measures and equipment reliability, and streamlines compliance with ISO-27001 [208], ISO55001:2014 [36], and ISO-19650, ensuring asset integrity and performance sustainability. Notably, it yields cost savings in operations and maintenance, crucial for financial optimisation under ISO-55001:2014 [36]. Additionally, AIM's facilitation of strategic planning and resource management, coupled with its role in promoting sustainable AM practices, aligns with ISO-19650's efficiency and sustainability goals. By validating Blockchain and AIM's impact on the AM lifecycle, particularly in enhancing operational efficiency in alignment with ISO-27001, ISO-55001:2014 [36], and ISO-19650 [2] standards, the chapter paints a future of AM marked by advanced technology, data-centricity, collaboration, and compliance. This future envisages setting new standards for operational efficiency, sustainability, and stakeholder engagement in AM. The subsequent chapter 6 provides a comprehensive analysis and discussion of the findings presented in Chapters 4 and 5.

Chapter 6

The Impact of Research

6.1 Introduction

Chapter 6 is a pivotal link between Chapters 2, 4, and 5, drawing upon the research background, aim, and objectives outlined in Chapter 1, including the research questions. This chapter discusses the opportunities and challenges associated with integrating BIM, AIM, and Blockchain technologies within the AM lifecycle. It synthesises the findings and discussions from the preceding chapters to provide a comprehensive understanding of how these technologies can transform the construction industry, particularly in the context of the KSA. By doing so, this chapter contributes to the field's knowledge and sets a direction for future research in sustainable construction practices, aligning with the overarching goals of enhancing efficiency, reliability, and transparency in construction project management and AIM.

6.2 Findings and Discussions

The initial sections of this discourse, precisely Chapter 2, align with the objectives outlined in Chapter 1, to define and explore the roles of BIM and AIM within AM. BIM is depicted as a digital representation of the physical and functional characteristics of an asset, serving as a reliable knowledge resource for information about a facility and thus supporting decisions throughout its lifecycle. AIM, on the other hand, extends the concept of BIM by encompassing comprehensive information relevant to the operational phase of the asset, ensuring access to detailed, accurate, and up-to-date information for AM purposes. BIM and AIM are collectively portrayed as foundational elements in the digital transformation of AM, enhancing decision-making, efficiency, and performance monitoring throughout the asset's lifecycle.

The integration of Blockchain technology, as detailed in the findings from Chapter 2, underscores its potential to enhance information management within the construction industry. This integration supports model-based project delivery and AM, with frameworks and models developed to ensure efficient handover of digital facility models, enhance security systems, and establish BIM policies for improved AM. The creation of a mind map titled "Enhancing Information Management with Blockchain in Construction" synthesises these findings, offering a structured overview of Blockchain's role in improving asset information management processes and, by extension, the AM lifecycle.

Hence, based on the above thematic analysis, integrating Blockchain into existing construction and AM workflows presents challenges, including scalability, interoperability with existing digital tools, and the need for industry-wide standards. The construction industry's traditional slow adoption of new technologies points towards innovation but also underscores the cultural and organisational changes required to embrace Blockchain technology fully. Moreover, a cost-benefit analysis is necessary for stakeholders to invest in Blockchain technology, with the mind map suggesting numerous benefits but not delving into the associated costs or whether the long-term benefits justify these expenses. Regulatory and legal considerations also play a crucial role in the widespread adoption of Blockchain in construction, involving complex legal and regulatory environments, especially concerning data privacy and the legal status of smart contracts. These aspects are crucial but not covered in depth in the mind map.

Finally, the future research directions based on the mind map serve as a foundation for identifying areas requiring further investigation, such as the development of specific Blockchain applications for construction, the integration of IoT with Blockchain for enhanced AM, and the exploration of Blockchain's role in sustainable construction practices. These insights directly inform the design and development of an integrated Blockchain-based tool, as proposed in Chapter 4, Objective 2.

This tool is envisioned to bridge the gap between the theoretical potential of Blockchain and its practical application in construction and AM. By integrating AIM and BIM within a Blockchain framework, the tool aims to address the identified challenges, including scalability, interoperability, and the need for industry-wide standards, while capitalising on the benefits of enhanced data integrity, security, and transparency. The researcher designed an Architecture to visualise how this Blockchain-based platform could integrate BIM and AIM, followed by a beta test exercise before its validation (Chapter 5). For the beta test, the researcher contacted a local company in Jeddah, in the Kingdom of Saudi Arabia, to test the demo. Based on the findings, the researcher derived several key insights and learnings about the integration of Blockchain within an AIM Environment, particularly in the context of the KSA. These insights span demographic data, experience levels, facilities management, AM importance, and the adoption of BIM.

Demographic and Experience Levels: The diversity in the professional background and experience levels of respondents [7], [9], [10], reflects a broad spectrum of perspectives on the integration of BIM and Blockchain technologies. Albejaidi and Nair [7], along with Albogamy et al. [5], highlight the challenges posed by the lack of in-house expertise in BIM adoption, underscoring the need for comprehensive training and development programs to bridge this gap. This is critical for fostering a deeper understanding and effective implementation of these technologies across the construction industry.

Integration of Blockchain: The potential of Blockchain to enhance the AIM Environment, as discussed by Hultgren and Pajala [209], and supported by Olnes et al. [31], points towards its capacity to facilitate outsourced facilities management services and improve the management of asset documents. However, the gap in equipping asset managers to adhere to ISO standards [64], effectively suggests a need for targeted educational initiatives and the development of clear guidelines to ensure compliance and maximise the benefits of Blockchain integration.

Asset and Facilities Management: There's a discernible emphasis on the importance of facilities management over AM per se, to maintain or enhance asset value. This aligns with the understanding that effective AM is crucial for business valuation, as per ISO-55000:2014 standards [36], [208], [210], and [64]. Yet, a low percentage of respondents consider AM to be important, indicating a potential area for improvement in perception and practice within the KSA compared to Western countries.

BIM Adoption: Recognising the necessity to invest in BIM compliance [19], [11], [26], and [103], throughout the project lifecycle, including AM, points to a growing awareness of its value. However, the discrepancy in the perceived value of BIM in improving facilities management versus AM underscores the need for enhanced BIM expertise and digital proficiency [211], [40], [44]. This gap in current practices necessitates focused efforts to elevate the role of BIM in asset operation and management, leveraging collaborative technologies to drive efficiency and sustainability.

Sustainability and Decarbonisation Efforts: A minimal percentage of the sample highlighted the importance of investing in hardware technologies, which poses a potential challenge for the industry's decarbonisation efforts [212], [115], [2]. The energy consumption and material usage associated with these technologies could hinder achieving Sustainable Development Goals (SDG) targets. In summary, the research highlights the potential advantages and existing challenges associated with integrating Blockchain and BIM throughout the AM lifecycle. It emphasises the importance of raising awareness, increasing adoption, and developing expertise in BIM and digital technologies to improve facilities and AM practices, ensure compliance with international standards, and support sustainability and decarbonisation initiatives (Chapter 2). Furthermore, the research, drawing on ISO-55000 data, identifies that the asset data most impacted during the asset lifecycle include the building's, energy, and long-term planning data (Chapter 4). Based on these insights, the study suggests that a Blockchain-based environment, coupled with integrating Blockchain and AIM, can optimise AM. Moreover, integrating Blockchain technology into the AM lifecycle, particularly in the Design and Build Phase, Handover Stage, and In-Use Performance Stage, significantly enhances AM processes' efficiency, reliability, and transparency. This integration is further elucidated by examining the extent of compliance with building details data and energy data in the operation stage, alongside long-term planning data throughout the AM lifecycle:

In the **Design and Build Phase**, Blockchain technology fosters mutual trust and transparency, which is crucial for recognising roles such as the information manager. It streamlines quality assurance and operational training, clarifying team responsibilities. As suggested by Volk et al., [49] the integration of RFID technology with AIM further enhances the tracking and management of physical assets, simplifying access to maintenance manuals and keys, thereby reducing defects and ensuring compliance with legal standards.

In the Handover Stage, the commissioning phase, the benefits of Blockchain in creating accurate and immutable records align with the findings of Yaga et al. [110], who highlight Blockchain's architecture and consensus mechanisms as foundational for ensuring data integrity and security. This capability is crucial for managing commission plans, building drawings, insurance data, and quality control documents, facilitating a smoother transition to operational AM. The emphasis on detailed compliance data resonates with the principles outlined in the National BIM Standard [11], which advocates for comprehensive documentation to support effective AM.

In the Use Performance Stage, Blockchain's impact on operational efficiency, health and safety, and equipment reliability is echoed in the work of Luo et al. [113], who explore the potential of smart contract-based Blockchain frameworks to automate construction payments, thereby enhancing operational efficiency and reducing costs. The focus on sustainability and life cycle costing is supported by the ISO-55000 series [64], [213], which sets out a framework for effective AM with a focus on long-term value creation. The importance of detailed and accessible data for energy efficiency and long-term planning is further underscored by the work of Zhu et al., [40], who discusses the role of Blockchain in digital AM, emphasising the need for distributed permission and access control to manage energy data effectively.

Henceforth, the compliance data (chapter 4,83) further highlights the necessity of detailed and accessible information for effective AM. For instance, the Extent of Compliance with the Building Details Data in the operation stage showcases the critical nature of maintaining comprehensive records on spare parts, manufacturer/vendor info, asset location, and more. Similarly, the Extent of Compliance with the Building Energy Data Details emphasises the importance of monitoring energy consumption patterns for heating, electricity, cooling, and water, which are essential for sustainable AM. Lastly, compliance with the Long-term Planning Data in the operation stage reflects the importance of planning for maintenance costs, understanding general facilities information, and maintaining up-to-date asset data. This comprehensive approach to documenting and managing detailed asset information supports implementing Blockchain and AIM technologies effectively, ensuring assets are managed efficiently, effectively, and sustainably throughout their lifecycle. Hence, now is the time to validate the impact of this integrated tool on AM. Chapter 5 (Objective 3) focuses on validating the impact of this integrated tool on the AM lifecycle. This validation process involves assessing the tool's effectiveness in improving decision-making, efficiency, and performance monitoring, as well as its role in facilitating the digital transformation of AM. The evaluation considered the tool's ability to overcome traditional construction and AM challenges, such as clash detection, late payments, and risk management, thereby enhancing stakeholder collaboration, transparency, and safety incentives. The researcher, on this basis, used a mixed-method approach to validate the results. Based on Table 5.6 (chapter 5, 107) a mind map was created to visualise the impact factor analysis of the integration.

Moreover, integrating Blockchain, BIM, and AIM throughout the AM lifecycle marks a pivotal advancement in AM practices, spanning from design and construction to operational use and maintenance. This study thoroughly examines the impacts these technologies exert across different phases of the asset lifecycle, underscoring both the benefits and strategic imperatives for their adoption. Moreover, the validation phase delves into the role of Blockchain in enhancing strategic decision-making and policy formulation within the BIM framework, evaluating its capacity to bolster overarching organisational objectives. This holistic assessment seeks to underscore the practical advantages of fusing Blockchain technology with AIM and BIM, laying a solid groundwork for its embrace within the construction sector and beyond. A critical analysis of the study's findings reveals the multifaceted benefits of integrating Blockchain, BIM, and AIM across various stages of the AM lifecycle, including:

Design and Build Stage: Integrating AIM and Blockchain technology at the Design and Build Stage heralds a paradigm shift towards increased efficiency and collaboration in construction projects. This assertion is underpinned by the systematic review by Menassa [214], which emphasises the evolution towards intelligent building representations, suggesting that Blockchain can enhance these models with its inherent qualities of security, transparency, and traceability [4]. The practical implications of such integration are supported by empirical evidence, as indicated by using Chi-square tests [205], [199], reinforcing the claims of improved time and cost efficiencies. This stage's focus on streamlined maintenance, precise location identification, and enhanced team collaboration echoes the findings of Hultgren and Pajala [209] and aligns with the broader objectives of improving productivity in the construction industry as outlined by Barbosa et al., [215].

Commissioning, Operations, and Maintenance Stage: At this stage, emphasising high-quality data and the necessity for stringent daily reporting is critical for aligning with international standards like ISO-27001 and ISO-55001:2014 [36] and [201]. This alignment signifies a move towards more regulated and standardised AM practices, reflecting a broader trend towards transparency, accountability, and sustainability in AM [15], [16]. The critical importance of data quality and reporting at this stage is a compliance requirement and a strategic imperative for enhancing the overall AM process, as suggested by the research on Blockchain's implications for information sharing in government [15].

In Use Stage: The In Use Stage is identified as having the greatest impact from integrating AIM and Blockchain, highlighting the benefits of enhanced AMS preparation, improved stakeholder collaboration, and increased cost-effectiveness [30] and [22]. This stage directly influences the operational efficiency and sustainability of the asset, underscoring the long-term benefits of integrating these technologies in AM. The emphasis on stakeholder collaboration and cost-effectiveness resonates with the findings of Kapogiannis and Sherratt [11], who noted the impact of integrated collaborative technologies on forming a collaborative culture in construction projects.

Furthermore, the focus on sustainability and the role of Blockchain in supporting decarbonisation efforts [2] and [189], aligns with the broader goals of achieving Sustainable Development Goals (SDG) targets, highlighting the critical role of technology in enhancing the sustainability of AM practices. Henceforth, integrating Blockchain, BIM, and AIM throughout the AM lifecycle marks a transformative approach to managing assets from design and construction to operational use and maintenance. This synthesis of technologies facilitates a more efficient, reliable, and transparent management process, addressing several critical challenges and opportunities identified in the thematic analysis. Here's a refined connection of these insights, emphasising the seamless integration and its implications across the asset lifecycle:

Streamlined Maintenance and Key Location Identification: The initial stages of design and construction benefit immensely from this technology. The facilitation of improved maintenance scheduling and precise key location tracking through Blockchain technology significantly enhances operational efficiency and reduces both time and cost [21]. This efficiency is a testament to Blockchain's potential to streamline the construction phase, making it more cost-effective and less time-consuming [6]. As supported by Blockchain, the ability to accurately track and manage assets in real-time aligns with the objectives of digital twins and intelligent building representations, furthering the AEC-FM industry's evolution towards more sophisticated AM practices [26].

Enhanced Team Collaboration: The collaborative environment fostered by the use of AIM and Blockchain is pivotal, ensuring that all project stakeholders have access to up-to-date, transparent, and immutable records of asset information [30] and [22]. This level of collaboration is essential for the success of projects, particularly in the complex scenarios of asset lifecycle management, where the coordination of various stakeholders is critical [34] and [11]. The integration of these technologies supports the creation of a unified platform for information sharing and decision-making, facilitating a more cohesive and efficient project management process.

Compliance and Quality Data: The emphasis on high-quality data and stringent daily reporting during the Commissioning, Operations, and Maintenance stage is crucial. It underscores the importance of adhering to international standards such as ISO-27001 and ISO-5501:2014 [17] and [19]. Blockchain is key in ensuring data integrity and security, paramount for achieving compliance and operational excellence [27]. This stage highlights Blockchain's importance in maintaining high data quality standards and compliance with regulatory requirements.

Significance of the 'In Use' Stage: The 'In Use' stage is identified as having the greatest impact, where the strategic use of smart contracts and a BIM execution plan significantly enhances AM System (AMS) preparation, stakeholder collaboration, and cost-effectiveness [19]. This phase benefits from optimising the operational phase of the asset lifecycle, showcasing the profound impact of integrating AIM and Blockchain in enhancing the efficiency and sustainability of AM [22]. The ability to automate and secure AM processes through Blockchain technology ensures a more sustainable and efficient approach to managing the built environment, aligning with the goals of sustainable development and the efficient use of resources [113].

Thus, this integrated Blockchain-based approach aims to revolutionise the AEC industry by addressing the implementation challenges, overcoming technology adoption barriers, considering cost implications, and navigating regulatory landscapes. It paves the way for a more streamlined, collaborative, and compliant AM lifecycle, highlighting the critical role of technology in shaping the future of construction and AM.

6.3 Key Implications (theoretical and practical)

The integration of BIM, AIM, and Blockchain technology within the AM lifecycle, as explored in the referenced literature, presents both theoretical and practical implications for addressing the research questions concerning their roles in the construction project lifecycle and the facilitation of AIM and management.

Theoretical Implications:

1. E**volution of Building Representations:** Menassa's systematic review [214] on the evolution from BIM to digital twins underscores the theoretical foundation for integrating BIM and AIM, highlighting the progression towards more intelligent building representations. This evolution provides a conceptual basis for understanding how Blockchain can further enhance these models by adding layers of security, transparency, and traceability [4].

2. **Blockchain's Role in Construction:** Hultgren and Pajala [209], along with Barbosa et al. [215], contribute to the theoretical understanding of Blockchain's potential to address transparency and traceability in the construction supply chain and its broader implications for improving productivity within the industry. These insights are crucial for conceptualising how Blockchain can facilitate AIM and BIM in managing asset lifecycles more efficiently.

3. **Addressing Industry Challenges:** The challenges facing the construction industry, as identified by Leeds [4]. and echoed in the Saudi Arabian context by Albejaidi and Nair [9], Albogamy et al. [5], and Khan and Khan [7], provide a theoretical backdrop for the necessity of integrating innovative technologies like BIM, AIM, and Blockchain. These challenges include the slow adoption of new technologies, scalability, interoperability, and the need for industry-wide standards, which Blockchain technology could potentially mitigate.

Practical Implications:

1. **Implementation in KSA:** The practical application of integrating Blockchain with BIM and AIM in Saudi Arabia, as discussed by Alofi et al. [20] and reflected in the broader goals of Vision 2030 [10], demonstrates the potential for these technologies to revolutionise AM practices in the region. The demographic data and experience levels [7] and the emphasis on facilities management [9] highlight the operational considerations and the need for in-house expertise to leverage these technologies effectively.

2. **Enhancing AM Practices:** The integration of Blockchain technology is shown to facilitate outsourced facilities management services, access to updated construction drawings, and better management of asset documents [6]. This practical application underscores the benefits of Blockchain in enhancing the efficiency, reliability, and transparency of AM processes, aligning with the theoretical implications of its role in the construction industry.

3. **Compliance and Standards:** The gap in equipping asset managers to adhere to ISO standards effectively [14], [211], and [120] presents a practical challenge that integrating Blockchain, BIM, and AIM seeks to address. By ensuring detailed and accessible information for effective AM, these technologies support compliance with international standards and promote sustainable construction practices [216] and [217].

4. **Future Research Directions:** The identified need for further investigation into specific Blockchain applications for construction [30], [22], and [21], the integration of IoT with Blockchain for enhanced AM [43], and Blockchain's role in sustainable construction practices [115] and [209] suggest practical pathways for future research. These directions are informed by the theoretical understanding of Blockchain's potential and its practical applications in the construction industry.

The beta–test of the Blockchain-Enabled AIM Environment done in this study demonstrated that the integration of Blockchain can significantly enhance the information delivery cycle as prescribed by ISO-19650, which provides a framework for managing information over the whole life cycle of a built asset using BIM. Here's how the AIM environment could add value:

1. **Security and Immutability:** Blockchain technology can ensure the security and immutability of data throughout the asset lifecycle, which is crucial during the delivery (pre-operation) and operational phases of a building or infrastructure asset.

2. **Enhanced Collaboration:** With AIM on the Blockchain, stakeholders have a reliable and consistent way to collaborate, as the information can be trusted and is verifiable. It ensures that the data is not tampered with from the time of its creation through to operation and potential repurposing or decommissioning.

3. **Improved Auditability:** Using Blockchain provides an auditable trail of all interactions with the asset's information. This enhanced traceability is invaluable for maintaining records throughout the various ISO-19650 stages, from briefing to in-use phases.

4. **Efficient Documentation Management:** The proposed system could facilitate the management of documentation, non-graphical data, and graphical models by allowing for streamlined sharing and version control, ensuring all parties work with the most up-to-date information.

5. **Transparency in Procurement:** By using Blockchain to manage the exchange of information during the procurement phase, there is increased transparency and reduced risk of disputes regarding the origin and integrity of the information shared.

6. **Smart Contracts:** In the execution phase, smart contracts can automate certain aspects of the BIM Execution Plan (BEP), contract awards, and

asset information requirements, ensuring that predefined conditions are met without manual oversight.

7. **Cryptography and Consensus Algorithms:** The application of cryptography and consensus algorithms ensures that the integrity of the asset information is maintained. This is especially important for the CDE, where data is shared among various stakeholders.

8. **Facilitates EIR:** The AIM system could ensure that the information delivered meets the EIRs by validating the compliance of the data against the set requirements using Blockchain technology.

9. **Regulatory and Standards Compliance:** Blockchain can assist in compliance with ISO-19650 by providing a clear structure for organising information and ensuring that all processes adhere to the standard's requirements.

10. **Energy Consumption and Scalability:** While Blockchain has its challenges with energy consumption and scalability, these can be managed within the AIM environment by choosing the appropriate consensus algorithm and considering the overall architecture of the Blockchain solution to be efficient and sustainable.

11. **Interoperability and Integration:** Blockchain can be designed to be interoperable with existing systems and facilitate the integration of various types of data and platforms within the AIM, thereby enhancing the ISO-19650 information delivery cycle.

By improving these aspects, the proposed Blockchain-Enabled AIM environment would add significant value to ISO-19650, potentially leading to better AM practices that are secure, transparent, and efficient.

In conclusion, integrating BIM, AIM, and Blockchain technologies holds significant theoretical and practical implications for transforming AM practices. Theoretically, it builds on the evolution of intelligent building representations and addresses key industry challenges. Practically, it offers a road map for implementing these technologies in contexts like Saudi Arabia, enhancing AM practices, ensuring compliance with standards, and setting directions for future research.

6.4 Contribution to knowledge

The PhD research presents a rich tapestry of academic contributions, integrating Blockchain with AIM and thus propelling the discourse in digital AM forward. Moreover, in the context of the ISO-19650 information delivery cycle represents a significant advancement in the field of AM, contributing to academic knowledge and industry practice in several key ways:

1. **Innovation in Asset Lifecycle Management:** The study investigates the impact of Blockchain technology on AIM, emphasising its potential to revolutionise asset lifecycle management, particularly in the operational phase. This contributes to understanding how Blockchain technology can enhance the integrity and reliability of asset data throughout its lifecycle.

2. **Statistical Analysis of Operational Efficiency:** Through comprehensive statistical analysis, the research quantifies the benefits of integrating Blockchain with AIM, such as improved collaboration and cost efficiency. This empirical evidence adds a layer of rigor to the argument for Blockchain's application in AM.

3. **Enhanced Collaboration Framework:** The study outlines a framework for facilitating stakeholder collaboration using Blockchain's decentralised ledger and smart contracts, which is particularly relevant for the operational phase of assets. This framework can serve as a blueprint for organisations looking to improve stakeholder engagement and project delivery outcomes.

4. **Strategic Recommendations for Technology Integration:** The provision of strategic recommendations for integrating AIM and Blockchain technologies contributes to the discourse on best practices in the digital

transformation of AM. This includes advocacy for smart contracts and an execution plan aligned with BIM, guiding future implementations.

5. **Technological Synergy:** By exploring the synergy between Blockchain and AIM, the study adds to the literature on how combining these technologies can offer more than the sum of their parts, providing a comprehensive solution for the challenges of managing complex assets.

6. **Advancements in ISO-19650 Compliance:** The research addresses how Blockchain can support compliance with ISO-19650, contributing insights into the standardisation of data processes in BIM and AM, and proposing methodologies to align Blockchain's capabilities with the requirements of ISO-19650.

7. **Smart Contract Security in AM :** Investigating the security of smart contracts within the AM domain adds to the body of knowledge on mitigating potential vulnerabilities in Blockchain applications. This includes exploring formal verification techniques and code reviews to ensure the reliability of these automated agreements.

8. **Environmental and Regulatory Implications:** The research not only celebrates the benefits of Blockchain but also critically examines the constraints and consequences of its adoption, such as scalability issues, energy consumption, and regulatory uncertainty. This comprehensive view is essential for a balanced understanding of the technology's potential and limitations.

In summary, this PhD research enhances the current understanding of digital AM by providing a detailed study of Blockchain's role in improving AIM systems, backed by statistical evidence and strategic frameworks. It also critically assesses the challenges and offers practical recommendations for overcoming these, thus offering a well-rounded contribution to the field.

6.5 Summary

Chapter 6 delves into the innovative amalgamation of Blockchain, BIM, and AIM within the realm of AM, illustrating the transformative impact these technologies could have on enhancing AM practices' efficiency, reliability, and transparency. Focusing particularly on the Kingdom of Saudi Arabia, this chapter explores the vast opportunities and significant challenges of technological integration in the field of AM. By weaving together BIM, AIM, and Blockchain, a novel and advanced methodology for AM is proposed, one that seeks to overcome current limitations and open new avenues for improving asset performance, reliability, and sustainability.

The insights and conclusions drawn offer valuable contributions to the body of knowledge on AM, presenting actionable strategies for professionals and organisations looking to capitalise on these cutting-edge technologies. Moreover, the chapter highlights the importance of addressing implementation challenges, including technology adoption barriers, cost considerations, and regulatory issues, thereby laying out a comprehensive guide for optimising the benefits of integrating AIM and Blockchain, particularly during the operational phase of asset lifecycle management.

Chapter 7

Conclusion

7.1 Introduction

This work extensively describes the research background, firstly, background and contract type in the construction industry, followed by pre- and post-BIM execution plans. Secondly, AIM and BIM have been explored. Similarly, the research background of facility management and Blockchain technology has been explored. This work has described the research methodological framework and methods. Thirdly, it has examined the different philosophical perspectives regarding social science research, followed by the choice of the philosophical position of the study. Fourthly, data collection methods have been described. Similarly, data collection methods and data analysis have been elaborated by providing clear approaches to be followed using the multi-method approach. The results aim to receive asset managers' input to ensure they feel comfortable and understand the added value of integrating Blockchain technology and AIMs into the AM lifecycle.

The researcher has used the data–information–knowledge–wisdom approach to developing the integrated AM environment. Following the design of the integrated systems; a Blockchain-based tool was developed in which smart contracts and AIMs were embedded. Practically, the research investigated whether and how AIM and Blockchain technology can improve the operational processes of an asset and thus support the stakeholders in construction projects. Cronbach's Alpha test has been used to ensure the consistency of the study sample observations to answer the questionnaire and to ensure its validity. This was followed by a set of descriptive statistical tests such as the arithmetic mean, standard deviation, and frequencies and logistic model regression to validate this study. The current study aimed to determine the interrelation between AIM and Blockchain in a construction project.

This work aims to improve the efficiency of AIM by storing and saving data related to construction projects. Additionally, this application improves AIM's functionality by storing the project's digital data. The contribution of this study is obvious as the resulting outcomes can be capitalised as guidelines to improve the AMP in the construction sector. This study has found that AIM, BIM, and Blockchain are nascent technologies. The limitation of skilled people is a challenge faced by adopting BIM and Blockchain technologies in the construction industry. Cost is the main challenge for Blockchain, AIM, and BIM. This is because clients are not willing to adopt new technologies in their businesses and projects.

7.2 Research Conclusion

The present study, however, makes several noteworthy contributions to the relationship between AIM and Blockchain in a construction project, which may require careful consideration of accuracy, collaboration, innovation, solutions, security, confidentiality, sharing, and trust. The results of this study indicate that the main features of applying Blockchain and AIM management are nonrepudiation, confidentiality, change tracking, recording, and data ownership. Therefore, using accurate data will help the asset owner to improve decision-making, optimise the use of operating assets, avoid misconceptions of culture and language between stakeholders, and support the asset process by eliminating waste. Blockchain could theoretically facilitate AIM and Management. This work constructs a new conceptual framework to manage, organise, store, and protect project information and data.

The Blockchain-based integrated AM environment has been tested with a well-oriented result that will add to existing knowledge in the management of the construction sector. The integration of AIM and Blockchain environment leads to better management and development of optimised transactions between the digital model and individuals. Several sectors are testing and exploring Blockchain technology in their processes, such as health care, finance, and government. However, this work focuses on the construction industry. Blockchain will help owners, consultants, contractors, and suppliers to upload and visualise the data from anywhere at any time throughout the lifecycle of the building to support the decisionmaking processes.

The project was undertaken to design a framework to create a decentralised "To-Do" application that allows the owner, consultant, contractor, and supplier to store and manage the AIM. This will provide technical support for effectively implementing AIM and Blockchain technology within internet web links, using methods and techniques based on databases and Blockchain technologies. This research also presented an AIM model in one platform, adding value to all stakeholders. In addition, it describes the relationship between AIR, BIM, PIM, OIR, and EIR in the integration and visualisation of AIM. To sum up, the Blockchain-based integrated AM environment shows the added value of utilising Blockchain technology throughout the AM lifecycle.

In addition, the proposed Blockchain technology throughout the AM lifecycle adds to our understanding of selecting specific data and information that will be used to measure the financial value gain/loss of a project concerning its cost. Moreover, it will enhance the user's ability to determine whether a project will yield a positive payback and have value for the business. Technically, framework features aim to improve the current management used in many ways, such as model upload/download, lack of data, partial model exchange, data security, multiple data model formats, and conflict resolution. From the validation point of view, the researcher found that Blockchain can record assets and ownership, thus integrating sensing platforms, smart contracts, and information models, enhancing tracking of maintenance and operation for physical assets. Tracking of changes and ownership of data are also significant benefits of applying Blockchain technology in the operations stage in the construction industry. The main aim of the proposed framework is to create a shared and transparent information platform.

The beta test aspect was successfully demonstrated in a framework involving documentation, non-graphical, and graphical models within a single platform to facilitate the owner's needs and achieve business goals. During the beta test process, the researcher measured an asset's financial value gain/loss with its cost. Moreover, it also enhances the user's ability to determine whether an asset would yield a positive payback and have value for the business, improving trust between stakeholders. Technically, the integrated environment features aim to improve in many ways the current way of management and issues such as model upload/download, lack of data, partial model exchange, data security, multiple data model formats, and conflict resolution. Thus, there seems to be improvement during the procurement process of the AM lifecycle.

In addition, results show that at the design and construction stage, the highest ranked point is the ability to use the information across the design/construction team, and the lowest ranked point is the maintenance manual and missing keys, while at the handover stage, the highest ranked point is equipment lists and the lowest ranked point is product data. Finally, at the operation stage, the highest-ranked points are health and safety, and the lowest-ranked points are cost savings and ROI.

The present study, however, makes several noteworthy contributions to the relationship between AIM and Blockchain in an asset that may require careful consideration of accuracy, collaboration, innovation, solutions, security, confidentiality, sharing, and trust. The results of this study indicate that the main features of applying Blockchain and AIM management are nonrepudiation, confidentiality, change tracking, recording, and data ownership. Therefore, using accurate data will help the asset owner to improve decision-making, optimise the use of operating assets, avoid misconceptions of culture and language between stakeholders, and support the asset process by eliminating waste. Blockchain could theoretically facilitate AIM and Management.

This research shows that a good 3D BIM model alongside detailed AIM, including Non-graphical data and documentation, could improve the AM lifecycle. However, the integration of Blockchain technology can impact the AEC sector to work more efficiently. This research showed that the direct impact of integrating AIM and Blockchain in AM is to offer a secure network that provides a trustworthy shared environment, where innovation can play a significant role and thus improve the delivery quality of digital and physical assets. So, Blockchain brings into construction a decentralisation culture of sharing construction project information over a secure integrated network. The study presented those factors affecting the operation of AIM throughout the asset lifecycle.

Among others in design and construction are improvement of trust, more appropriate quality assurance methods, and procedures saving time, optimising defect analysis, improving stakeholder's influences; in hand over process products' accurate data manufacturer; in operation process increase speed of preparing holistic and integrated AMS, improve collaboration between stakeholders, return faster clients' Return of Investments and finally save operational assets' costs.

Therefore, the novelty of this work is understanding the factors affecting the operation of asset information models throughout the assets' lifecycle by integrating Blockchain. Working in a secure cloud-based environment results in improved management of assets over a digital environment that allows investors and asset managers to pre-identify operational risks and utilise better assets resources.

Finally, it was noted how well ISO19650 and ISO55000 could work complementary to support better AM operations using an integrated collaborative culture. This could be the future of AM, where an integrated collaborative culture within a client-based environment could help them manage their assets' lifecycle in a more "intelligent" way. This is where Artificial Intelligence will be integrated and tested in future research to create Intelligent AM Strategies. Based on these features and specifications, the researcher designed and developed a Blockchain-based environment where the AIMs are integrated and offer a collaborative environment to asset managers to make better decisions and solve problems. This was validated through a workshop on an experiment in the Kingdom of Saudi Arabia. This allows the owner, consultant, contractor, and supplier to upload and visualise the data anywhere at any time throughout the lifecycle of the building. The findings also came out with a set of certain types of building data that are recommended to be digitalised and offered to asset managers, to offer high-end services to the owners.

The integration of AIM and Blockchain environment leads to better management and development of optimised transactions between the digital model and individuals. This research presents an AIM model in one platform, adding value to all stakeholders. In addition, it describes the relationship between AIR, BIM, PIM, OIR, and EIR in the integration and visualisation of AIM. Several sectors, such as health care, finance, and government, are testing and exploring Blockchain technology in their processes. However, this work focuses on the construction industry. Blockchain aims to help owners, consultants, contractors, and suppliers to upload and visualise the data from anywhere at any time throughout the lifecycle of the building to support the decision-making processes. The project was undertaken to design a framework to create a decentralised "To-Do" application that allows the owner, consultant, contractor, and supplier to store and manage the AIM. This will provide technical support for implementing AIM and Blockchain technology effectively within internet web links, using the methods and techniques based on the database and Blockchain technologies.

7.3 Research Contribution to Knowledge

This research contributes to the body knowledge in four aspects:

1. **In the construction industry (research area):** The type of this pose work focuses only on building construction. From a process point of view, this work contributes to the design team by allowing them to be deeply involved in the project lifecycle. Therefore, it will improve their knowledge to perform and introduce a high level of design quality. From a legal point of view, construction has a complex net of contracts and other obligations, all the stakeholders must carefully consider their conditions and targets. Therefore, the tool of this study fits into Saudi law and regulations and others. In addition, this research focuses on public projects in the KSA, within the design and build of the type of project lifecycle. This research integrates a decentralised and centralised environment in one source to improve project delivery.

2. **Methodology:** In this regard, the logic of this work is based on the deductive approach in positivist philosophy. The experiment will be across multiple disciplines, adding to knowledge in using areas related to the construction sector. Having a full package of the Mandatory Information Deliveries (MID) in the construction processes will lead to actual estimation cost, accurate scheduling, efficient communication, a high level of technical planning, better team skills, and soft handover and project closeout.

Recently, 1990's the use of coordination in the construction industry was highly recommended; in the middle of the 2000's, the use of integration in the construction industry was highly incentive, the revolution of the technology era and to meet Saudi Vision 2030 is necessary to work in a cooperation environment between all the stakeholders.

3. **Solve trending issues:** This research will contribute to solving unsolved problems facing the construction industry in many ways such as coordinating the project participants, which will reduce rework and share the information between the stakeholders to get their business done. Collaboration between them will also lead to information sharing being smooth. The design of a secure-based, integrated, and innovative environment that allows better acquisition project management lifecycle. Therefore, this research impacts FM and operation stages based on AIMs. This leads to and solves an essential aspect of making decisions within a fragmented, insecure building process.

4. **Developing a unique approach (tool):** Integrating a human-centric approach within a techno-driven environment (known as transdisciplinary engineering) can become the new trend for the future of the Built Environment. Recently, we have seen RICS and Cambridge University working towards Digital Twins and its process. For that reason, accurate asset data acquisition – storage – management (Blockchain), interoperable software, and capable people can work in a secured environment to support AM in a core comprehensive way. This could be a debate as the start of exploring Digital AM more (but this is not the focus of this research). Therefore, its novelty in providing a holistic human-centric approach allows stakeholders to work on a trustworthy system that enables better collaboration. This is due to the involvement of the latest information and communication technologies. Blockchain and BIM management will allow expert people to manage their project information effectively. In addition, Blockchain can

help to improve the stakeholders' ability to do the right business; hence, the developed AIM management is a tool to enhance the project's performance. In this scenario, this piece of work is to create a new tool aimed to manage, organise, store, and protect project information and data in a way to be:

- Accessible at any time,
- Organise to reduce the time for searching,
- Stored in a safe place, and
- Sustainable with different climate change.

The concept of this work is deemed to validate and be well result-oriented; therefore, it will add to existing knowledge in the construction area. This will lead to future research in construction technology by improving the IT capabilities of construction experts.

7.4 Recommendations and Future Work

Based on the findings presented throughout this study, recommendations for the KSA Construction Industry can be drawn from the framework and addressed by implementing the framework into policy. A future study investigating the added value of utilising Blockchain technology during the AM lifecycle would be fascinating, as would its production and maintenance of the system. Future work will include investigating the interrelation between AIM and BMS. The proposed framework will be used for FM involvement in the same platform to measure how relevant the data is to their needs and requirements. This study uses the energy management field as a proof of concept. It contributes to future projects in data management related to other fields.

7.5 Research Limitations

This study focuses on the Saudi Arabian construction industry and presents certain limitations that are important to acknowledge. While it serves as a case study with potentially broader applicability, the general usability of its findings to other countries or contexts may be constrained. The investigation aimed to enhance the AM lifecycle through the adoption of BIM, AIM, and Blockchain technologies. However, a significant limitation was the scarcity of skilled personnel proficient in these technologies, which poses a challenge to their widespread adoption within the industry.

Additionally, the cost associated with implementing Blockchain, AIM, and BIM technologies represents a major obstacle. This is largely due to client hesitation towards investing in new technologies, compounded by uncertainties regarding the financial ROI for AIM and Blockchain. These challenges notwithstanding, the research methodology employed—a multi-method approach—was meticulously detailed, offering clarity on the data collection and analysis methods used. This approach underscores the research's commitment to a structured and directed study, even as it navigates the above-mentioned limitations.

7.6 Concluding Comments

The current study aims to explore the interrelation between AIM and Blockchain within the context of a construction project. This work aims to improve the efficiency of AIM by storing and saving data related to construction projects. Additionally, this application improves AIM's functionality by storing the project's digital data. The contribution of this study is obvious as the resulting outcomes can be capitalised as guidelines to improve the AMP in the construction sector. The limitation of skilled people is a challenge faced by adopting BIM and Blockchain technologies in the construction industry.

Cost is the main challenge for Blockchain, AIM, and BIM. This is because clients are unwilling to adopt new technologies in their businesses and projects. However, the ROI of AIM and Blockchain is still not clear for the benefit of clients. The present study, however, makes several noteworthy contributions to the relationship between AIM and Blockchain in a construction project, which may require careful consideration of accuracy, collaboration, innovation, solutions, security, confidentiality, sharing, and trust.

The results of this study indicate that the main features of applying Blockchain and AIM management are nonrepudiation, confidentiality, change tracking, recording, and data ownership. Therefore, using accurate data will help the asset owner to improve decision-making, optimise the use of operating assets, avoid misconceptions of culture and language between stakeholders, and support the asset process by eliminating waste. Based on these features and specifications, the researcher aims to design and develop integrated AIMs by testing whether and how permissioned Blockchain could add value to construction projects in the KSA. This allows the owner, consultant, contractor, and supplier to upload and visualise the data anywhere at any time throughout the lifecycle of the building.

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Appendix A

List of Abbreviations

AEC	Architecture, Engineering, and Construction
AIM	Asset Information Modelling
AIP	Asset Information Processes
AIR	Asset Information Requirements
AM	Asset Management
BIM	Building Information Modelling
BMS	Building Management Systems
CDE	Common Data Environment
CP	Construction Procurement
EIR	Employers Information Requirement
FM	Facility management
IFC	Industry Foundation Classes
IT	Information Technology
KAAU	King Abdul-Aziz University
KPI	Keys Performance Indicator
KSA	Kingdom of Saudi Arabia
OIM	Organization Information Management
OIR	Organization Information Requirements
OSI	Open Systems Interconnection
PIM	Projects Information Model
PLC	Programmable Logic Controller
PMO	Program Management Office
ROI	Return on Investment

Appendix B

Workshop questions

Full access available:
https://forms.gle/DtRPb43DosmnNiDT7

1. Your Experience?

- 0-5
- 5-10
- 10-15
- 15-20
- 20 (More then 20)

Figure B.1: *Question 1.*

2.Please indicate (the equivalent of) your highest academic Qualification?

- High School
- Diploma
- Bachelor
- Postgraduate
- Other...

Figure B.2: *Question 2.*

3.Which of the following best describes your company's principal business activity?

- ○ Owner
- ○ consultant
- ○ contractor
- ○ supplier IT

Figure B.3: *Question 3.*

4.Length of time your organization has been using Building Information Modelling?

- ○ (0-1)
- ○ (1-2)
- ○ (2-3)
- ○ (3-4)
- ○ (more than 5).

Figure B.4: *Question 4.*

5.How would you assign most responsibility for building information handover to each of the following parties?

- ○ Owner
- ○ consultant
- ○ contractor
- ○ supplier
- ○ IT

Figure B.5: *Question 5.*

6. How important is the Project handover stage for your organization and your client?

- ☐ Extremely Important
- ☐ Very Important
- ☐ Important
- ☐ Not Important

Figure B.6: *Question 6.*

7.Which of the following present the most significant challenge to improve the operational process of an asset in the KSA? Please score on a scale of 1-5, where 1 is "most significant challenge" and 5 is "least significant challenge"

	1	2	3	4	5
Lack of mutual trust, and recognition of new project roles, such as information manager	☐	☐	☐	☐	☐
Inappropriate quality assurance methods and procedures	☐	☐	☐	☐	☐
Lack of transparency and accessibility of project data for all project team electronically	☐	☐	☐	☐	☐

Figure B.7: *Question 7.*

8.How significant are the following benefits to improve the operational process of an asset in the KSA? Please rank on a scale of 1-5, where 1 is 'most significant benefit' and 5 is 'least significant benefit

	1	2	3	4	5
Minimize defects	☐	☐	☐	☐	☐
Cost reduction	☐	☐	☐	☐	☐
Control construction process	☐	☐	☐	☐	☐
Save time	☐	☐	☐	☐	☐
Legislation and legal requirements	☐	☐	☐	☐	☐

Figure B.8: *Question 8.*

9.How important is the following project data at the operation stage? Please score on a scale of 1-5, where 1 is 'most important role' and 5 is 'least important role'

	1	2	3	4	5
Commission plans	☐	☐	☐	☐	☐
Building drawings and specification	☐	☐	☐	☐	☐
Insurance	☐	☐	☐	☐	☐
Manufacturer	☐	☐	☐	☐	☐
products data	☐	☐	☐	☐	☐

Figure B.9: *Question 9.*

10Which of the following could be affected mostly by the building operation process? Please rank on a scale of 1-5, where 1 is 'most affected' and 5 is 'least affected'

	1	2	3	4	5
Health and safety	☐	☐	☐	☐	☐
Reliability of equipment	☐	☐	☐	☐	☐
Standard of operations	☐	☐	☐	☐	☐
Cost of operations	☐	☐	☐	☐	☐
Cost of maintenance	☐	☐	☐	☐	☐
Better planning	☐	☐	☐	☐	☐

Figure B.10: *Question 10.*

11.Do you get the necessary information about the process of the project at every stage of operation?

☐ Yes

☐ No

Figure B.11: *Question 11.*

12.Is your facility maintenance outsource or do you perform this function in-house?

☐ Outsourced

☐ In-house

Figure B.12: *Question 12.*

13.Do you have easy access to all construction drawings, which are revised and updated?

- Yes
- No

Figure B.13: *Question 13.*

14.Have you got drawings to indicate location of your key Mechanical, Plumbing and Electrical installations?

- Yes
- No

Figure B.14: *Question 14.*

15.Do you have easy access to the project specifications?

- Yes
- NO

Figure B.15: *Question 15.*

16.Do you have easy access to the project warranty information?

- Yes
- NO

Figure B.16: *Question 16.*

17.Do you have easy access to the project service contracts?

- Yes
- NO

Figure B.17: *Question 17.*

18.Do you have easy access to the project spare parts data?

- [ ] Yes
- [ ] NO

Figure B.18: *Question 18.*

19.Do you have easy access to the project equipment Purchase date?

- [ ] Yes
- [ ] NO

Figure B.19: *Question 19.*

20.Do you have easy access to the project emergency management plans?

- [ ] Yes
- [ ] NO

Figure B.20: *Question 20.*

21.Are you satisfied with quality of information that is handed over to project owners towards completion of the project?

- [ ] YES
- [ ] NO

Figure B.21: *Question 21.*

22.What is your biggest facility challenge?

- [ ] Maintenance of facility budget
- [ ] Asset management and maintenance
- [ ] Emergency preparedness

Figure B.22: *Question 22.*

23.What investments are necessary to ensure effective implementation of Building operation?

- ◯ Development of BIM Processes
- ◯ Training of personnel
- ◯ Training in use of software
- ◯ Investments in Hardware (e.g. Tablets, Mobile Devices)
- ◯ Development of decentralised application
- ◯ Addressing software customisation/Interoperability Issues
- ◯ Other

Figure B.23: *Question 23.*

24.To what extent do you comply with the following data required to be optional or conditional at the operation stage: A- Type of data required / Building details

	Optional	Conditional
Area /Volume	☐	☐
Design criteria	☐	☐
Spare part information	☐	☐
Manufacturer/ vendor info	☐	☐
Asset location	☐	☐
Building use type	☐	☐

Figure B.24: *Question 24 (A).*

B- Energy data

	Optional	Conditional
Energy consumption heating	☐	☐
Energy consumption electricity	☐	☐
Energy consumption cooling	☐	☐
Water consumption	☐	☐
Locations of the control panels	☐	☐

Figure B.25: *Question 24 (B).*

C- Contract management

	Optional	Conditional
Warranty info	☐	☐
Replacement cost	☐	☐
Legal regulations and compliance	☐	☐
Purchase information	☐	☐
Life cycle cost	☐	☐
Certifications	☐	☐
Sustainability performance	☐	☐

Figure B.26: *Question 24 (C).*

D- Long term planning

	Optional	Conditional
Planned maintenance costs all types	☐	☐
Planned maintenance costs all types- subtasks	☐	☐
Facility general information	☐	☐
Row 4	☐	☐
Type of data required	☐	☐

Figure B.27: *Question 24 (D).*

Appendix C

Experiment

Figure C.1 is a snapshot of CAD to show the geometry details and measurements. However, the researcher has added this snap as an example of how the AIM virtual environment will be presented:

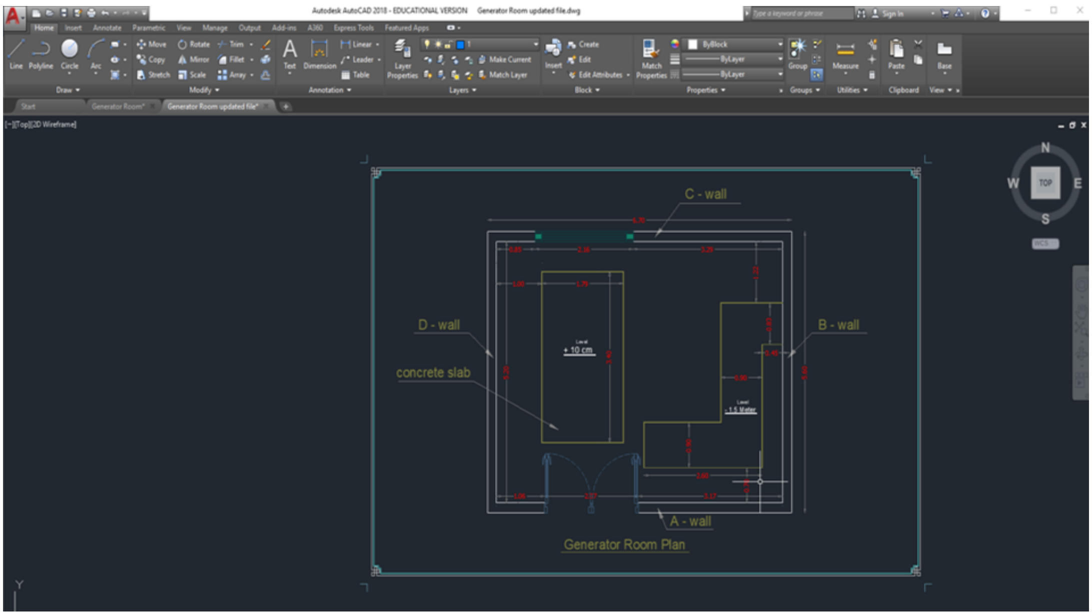


Figure C.1: *Capture of CAD platform*

Figure C.2 is a snapshot of a Revit model to show the internal 3-D model, while Figure C.4 shows the processes of testing and commissioning the current generator to work efficiently per the regulations and standards. However, the researcher has added this snap as an example of how the AIM virtual environment will be presented in the following snaps:

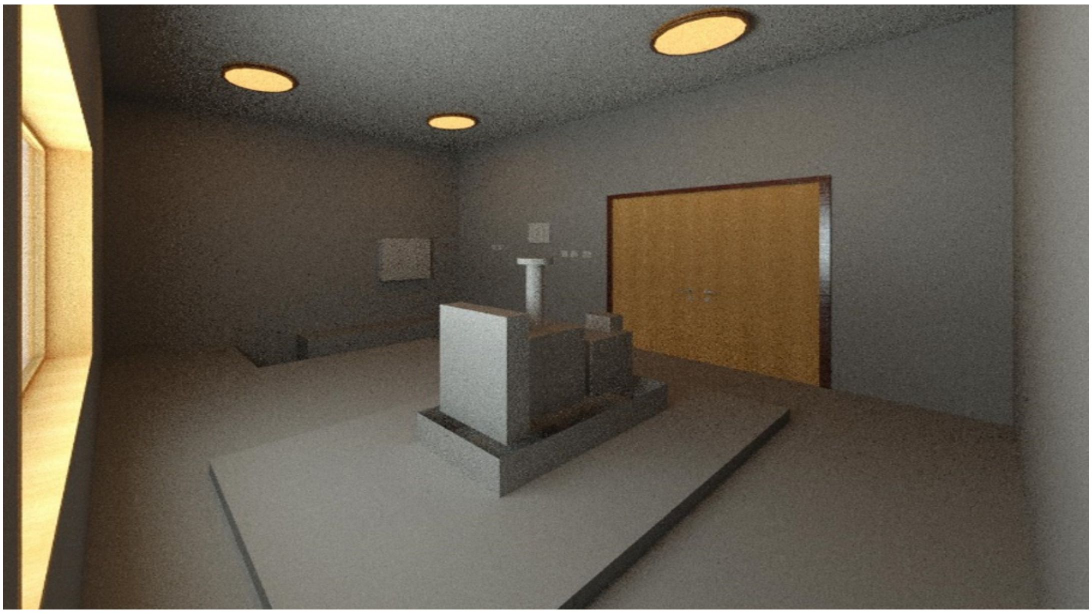


Figure C.2: *Capture of 3D Model*

Figure C.3: *Capture of Sketchup model*

Figure C.4: *Capture of recorded video for test & commission.*

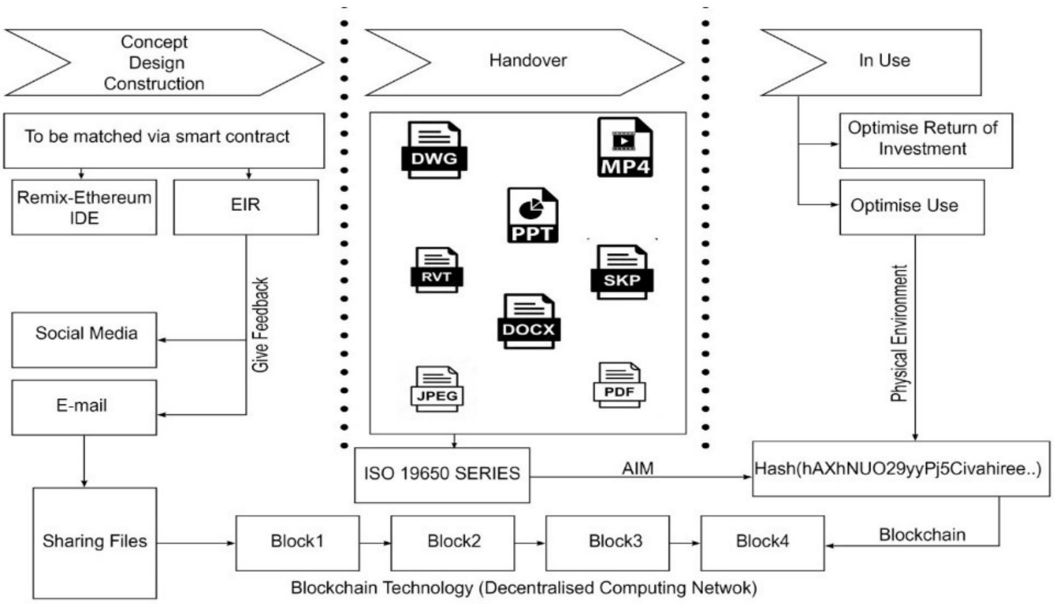


Figure C.5: *system design.*

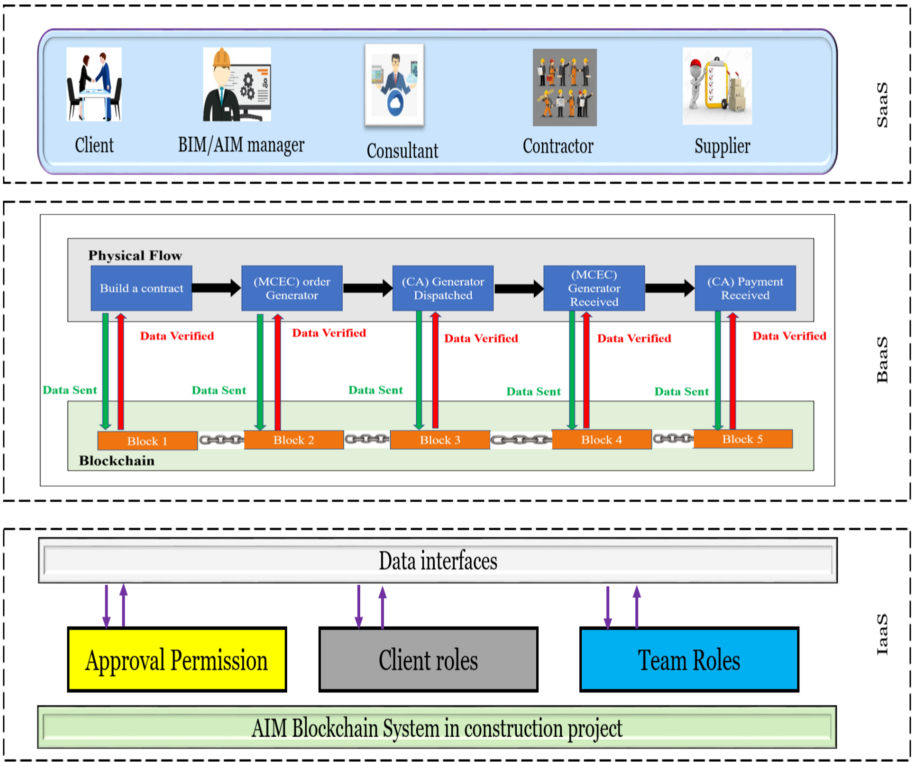


Figure C.6: *System Architecture Diagram.*

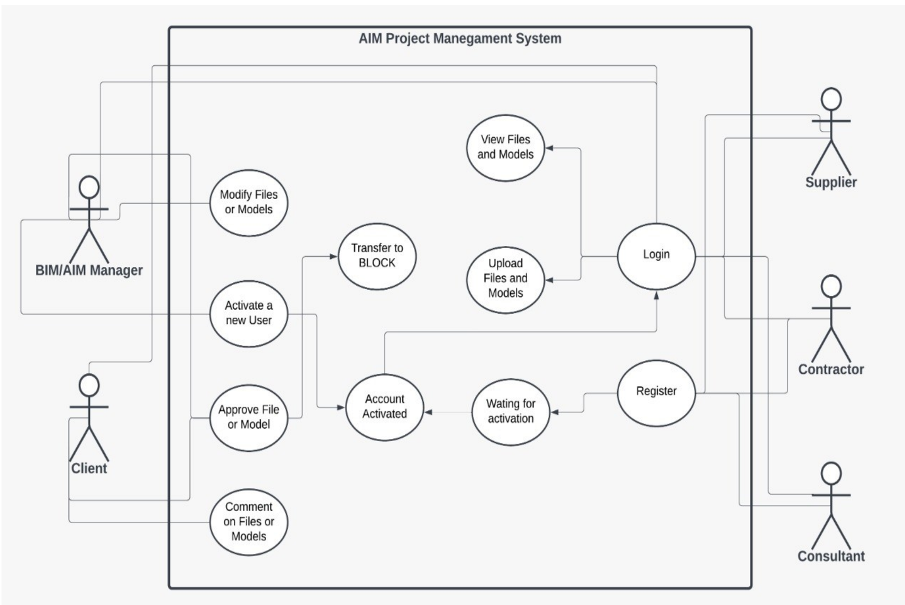


Figure C.7: *Global Use-Case Diagram.*

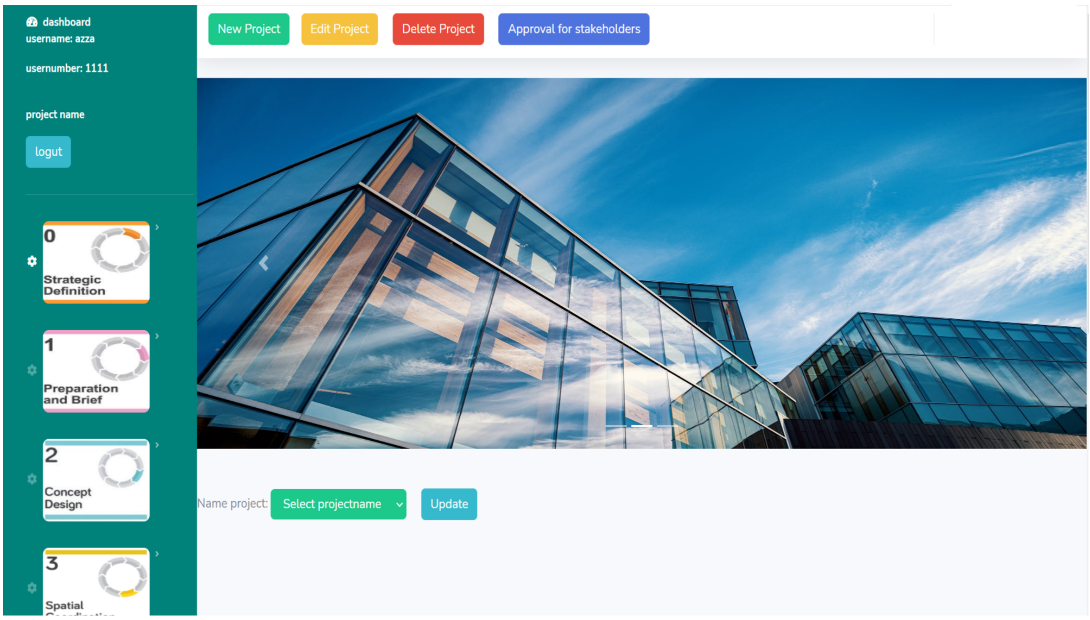


Figure C.8: *Platform interface.*

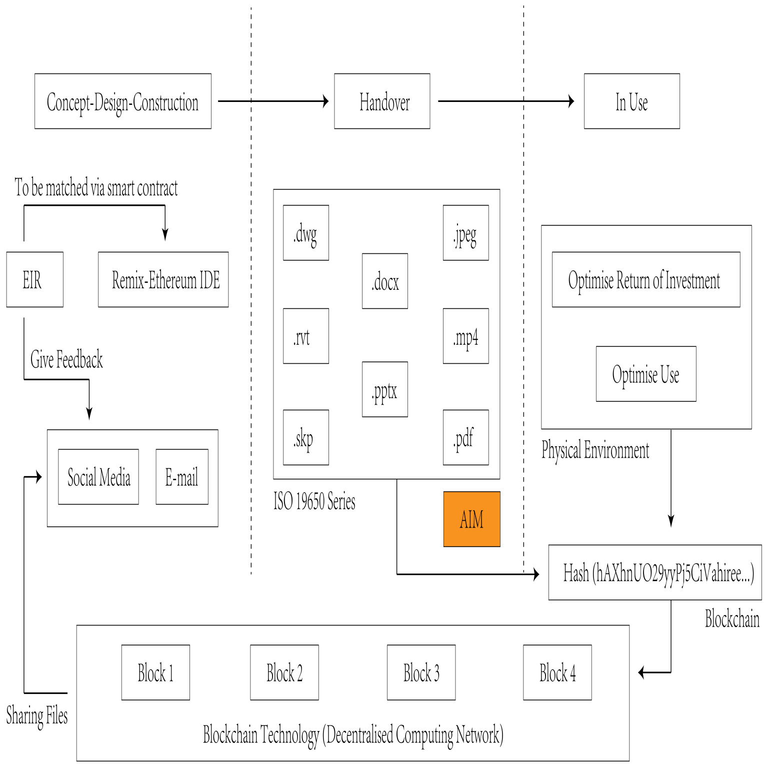


Figure C.9: *Optimise end user (asset/facilities management team) experience.*

<table>
<tr><th>Stage</th><th>Screenshot</th><th>Action</th><th>Description</th></tr>
<tr><td>0</td><td>Table 4.1: Beta Test Accounts
<table>
<tr><th>Email</th><th>Password</th><th>Role</th></tr>
<tr><td>projectmanager@test.com</td><td>Testing321</td><td>Project Manager</td></tr>
<tr><td>consultant@test.com</td><td>Testing321</td><td>Consultant</td></tr>
<tr><td>supplier@test.com</td><td>Testing321</td><td>Supplier</td></tr>
<tr><td>contractor@test.com</td><td>Testing321</td><td>Contractor</td></tr>
<tr><td>client@test.com</td><td>Testing321</td><td>Client</td></tr>
</table></td><td>Create Accounts</td><td>Beta Test Accounts," serves as an important tool for the 5 users participating in the beta testing of the software platform. It provides a set of credentials for different user roles—Project Manager, Consultant, Supplier, Contractor, and Client—each with the same password for simplicity during the testing phase.

To use these credentials within the interface, a beta tester would select the role that they are assigned to or interested in testing. They would then enter the email address and password listed in the table to log into the platform. For instance, a tester assuming the role of Project Manager would log in using the email "projectmanager@test.com" and the password "Testing321."

Once logged in, the tester would be able to explore functionalities and permissions associated with their specific role. This could include creating and managing projects for a Project Manager, accessing consultancy modules for a Consultant, viewing supplier-related information for a Supplier, managing contract details for a Contractor, or observing client-side features for a Client.

It's crucial that each tester sticks to their assigned role to ensure that the permissions and user experience for each role are accurately tested and documented. After testing, users typically provide feedback on the user</td></tr>
</table>

Figure C.10: *Stage 0*

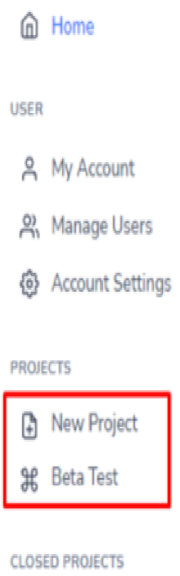
			experience, any bugs encountered, and suggestions for improvements before the platform goes live.
1		Create Project	The user begins by navigating the clearly structured menu within the system's interface. Upon logging in, they are greeted with the "Home" dashboard that provides a snapshot of the most relevant actions at their disposal. The "USER" category is neatly organized, allowing the user to access their personal account details under "My Account," manage other users' access and roles via "Manage Users," and adjust their own account settings in "Account Settings." Moving to the "PROJECTS" section, the user can view their active projects. The "New Project" function, which is accentuated by a red box in the screenshot, indicates its significance as the starting point for initiating new work. When the user selects this option, they are guided through the process of setting up a new project—defining its parameters, assigning team members, and establishing project milestones. The "Beta Test" listed below is likely a sample project provided for users to familiarize themselves with the system's features and functionalities. It may contain dummy data or a tutorial guiding the user through various features of the platform. The menu also includes a "CLOSED PROJECTS" section, where completed or inactive projects are archived. This keeps the workspace organized and focused on current tasks while still allowing access to past records for reference or audits.

Figure C.11: *Stage 1*

			In summary, the interface is designed to provide an intuitive user experience, facilitating the management of projects from conception to completion. The navigation menu is an essential component, enabling efficient access to various functions of the system with ease and precision.
2		Create Project Form	The "Create Project Form" displayed in Figure 4.11 provides an interface through which a user can input necessary details to initiate a new project. In this form, the user assigns the project a name, "Beta Test", and fills in other project specifics such as the location and a succinct description. The project's commencement and conclusion are scheduled with precise dates, setting clear timeframes for project execution. Participants in various capacities are allocated to the project by selecting their associated email addresses. For example, the form shows selections for a consultant, a contractor, and a supplier, each tied to a standardized test email. These roles are pivotal for the collaborative aspect of the project, allowing for a diversified team to manage different segments of the project lifecycle. The interface also enables the user to choose a project manager from a dropdown menu, which in this case is the 'projectmanager@test.com' account, granting them oversight responsibilities for the project. A unique identifier, the project code 'AIM-0012', is used to catalog the project within the system's framework.

Figure C.12: *Stage 2*

			A predefined budget is set, allowing for financial tracking and resource allocation throughout the project duration. The client associated with the project is specified as 'client@test.com', ensuring clear communication channels are established. After all the required fields are accurately completed, the user has the option to finalize the creation of the new project by selecting the 'Create Project' button or to halt the process by clicking 'Cancel'. This systematic approach to project creation aids in the meticulous organization and management of project details, facilitating an effective workflow within the system.
3		Project Main Home Page	The interface depicted in the screenshot provides users with an overview of a project, in this case, titled "Beta Test Project". It is part of the AMI-ASES system, as indicated in the top corner. The dashboard presents a range of project statistics and progress metrics in a clear, visual format. Upon accessing this dashboard, a user can immediately ascertain the current phase of the project, the assigned project manager, the allocated budget, total files associated with the project, and the number of team members involved. For instance, key statistics like project progress are represented both numerically and graphically, making it easy to gauge the completion status at a glance. The "Project Files Log" section presumably logs all interactions with the project's documents, allowing for real-time tracking of updates, modifications, or uploads to the

Figure C.13: *Stage 3*

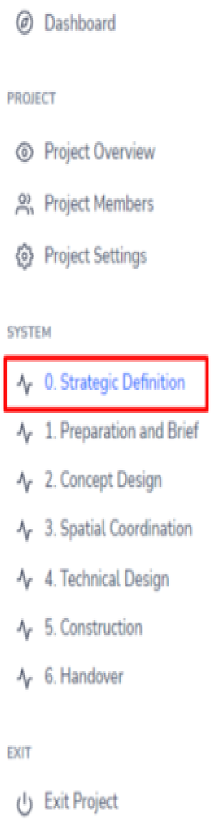
			system. This aspect of the interface is crucial for maintaining version control and ensuring all team members are working with the most current information. This dashboard serves as a centralized hub where the user can monitor all facets of the project's progress and access tools necessary for project management. Such an interface is instrumental in enhancing the efficacy of project management, streamlining communication, and facilitating the timely completion of project objectives.
4		Asset Management Strategic Definition Page	The navigation menu presented in the screenshot organizes the stages within the asset management lifecycle in the platform. The user can navigate through various options categorized under "PROJECT" and "SYSTEM," with a distinct section for "EXIT" at the bottom. Within the "PROJECT" category, the user can access the "Dashboard," "Project Overview," "Project Members," and "Project Settings." These sections allow the user to oversee the project from different angles, be it a bird's eye view of the overall project, the team composition, or the customizable settings particular to the project at hand. The "SYSTEM" category lists out the sequential stages of the asset management lifecycle, starting from "0. Strategic Definition" and culminating in "6. Handover." Each stage is checked off, suggesting progression through the asset management lifecycle. The "Strategic Definition" stage, specifically accentuated with a red box, may signal

Figure C.14: *Stage 4*

			its current status or underscore its significance within the lifecycle. The user utilizes this menu to smoothly transition between the different stages of the asset management lifecycle, effectively managing tasks and accessing pertinent documentation for each stage. The inclusion of the "Exit Project" option ensures that the user has a straightforward method to leave the project environment when their tasks are completed or when they need to step away. In essence, this user interface is thoughtfully tailored to enhance the management efficiency of the asset lifecycle, ensuring that users have ready access to critical information and can maintain organizational processes effectively.
5		Upload file page	The screenshot showcases a user interface within the asset management platform, specifically designed for the 'Strategic Definition' phase of the asset lifecycle. The user at this stage is provided with a straightforward mechanism for uploading relevant AIM and other files to the system. In the first step, marked "STEP 1: Upload Your File," the user can either drag and drop files into the designated area or use the browse function to select files from their computer. This flexibility ensures that the user can upload documents in the manner most convenient to them. Following the file selection, "STEP 2: File Name" prompts the user to enter a descriptive name for the file being uploaded. This is a crucial step, as proper naming conventions facilitate

Figure C.15: *Stage 5*

			easier retrieval and organization of documents within the system. Below the upload section, the interface presents a table where the operator's role, file names, date/time of file upload, file types, and available actions are listed. This tabulated format allows the user to manage uploaded files efficiently, offering the capability to perform actions such as reviewing, editing, or deleting the files as necessary. The interface exemplifies a user-centric design, focusing on ease of use and efficiency, which is vital in ensuring that the asset management process is not only meticulous but also user-friendly, allowing for precise management of the initial stages of the asset lifecycle.
6		During upload file	In the updated user interface of the asset management system, displayed in the screenshot, the user is situated in the 'Strategic Definition' phase. Here, the interface guides them through the process of contributing files pertinent to this stage of the asset lifecycle. The interface is laid out in a sequential two-step process. For 'STEP 1: Upload Your File,' the user is presented with a green-bordered box indicating an active or successful upload state, given the appearance of a file labeled 'sample.pdf' within the box. It suggests that the user can drag and drop their files into this area or opt to browse their system to select files manually. Following the successful selection of a file, the interface prompts the user to

Figure C.16: *Stage 6*

			enter the file's name in 'STEP 2: File Name,' where the placeholder text 'Test file' has been entered. It indicates the importance of clearly naming files for easy identification and retrieval within the system. Below these steps, the interface displays a table summarizing the uploaded files. The table lists out the operator, role, file names, the date and time of upload, file types, and a column for actions. These actions may include editing, sharing, or deleting files, providing the user with complete control over the document management within the 'Strategic Definition' phase. This interface is designed to ensure that the user's interaction with the system is not only intuitive but also effective in maintaining the organization and accessibility of critical documents at the commencement of the asset management process.
7		Page after the file is uploaded	The image presents an interface from the AMI-ASES system where the user is informed that their file upload has been successful, as indicated by the notification at the top of the screen. This alert is a key feature, providing immediate feedback on the user's action, which in this case is the upload of a file during the 'Strategic Definition' phase of the asset lifecycle. Within this interface, the user navigates through a two-step process to manage project documents. In 'STEP 1: Upload Your File,' a drag-and-drop area coupled with a browse option is available for the user to add new files to the system. Following the upload, the user enters a descriptive name for the

Figure C.17: *Stage 7*

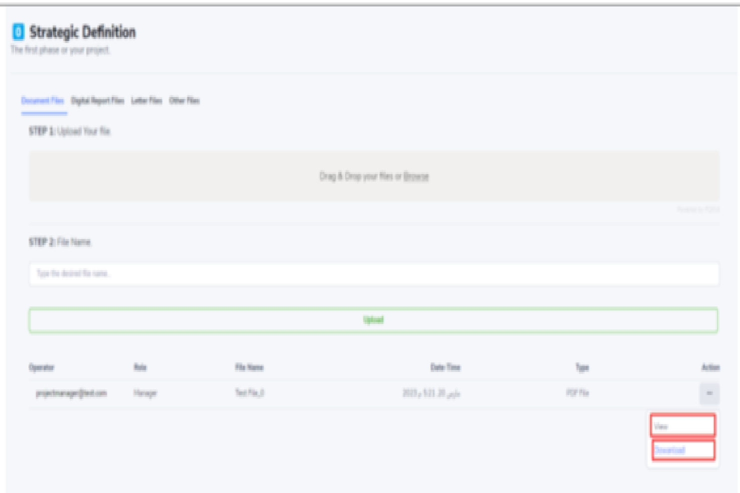
			document in 'STEP 2: File Name', ensuring that the file can be easily identified later on. Below these steps, the user can see a table that lists the uploaded files with details such as the operator's email, role, file name, date and time of the upload, file type, and actions available. The file named 'Test.pdf' uploaded by 'projectmanager@test.com' is now visible, allowing the user to perform actions like editing or deleting the file, as evidenced by the icons in the 'Actions' column. This streamlined and user-friendly interface ensures that users can efficiently manage documents related to the strategic definition of their project, maintaining an orderly and effective documentation process.
8		File Action	In the captured image of the asset management platform's interface, the user is at the 'Strategic Definition' stage of the asset management lifecycle. The interface is designed to facilitate the user's task of uploading documents relevant to this initial phase. The process is broken down into two steps for clarity and efficiency. "STEP 1: Upload Your file" presents a box where users can upload their documents by either dragging and dropping them into the space provided or by browsing their computer's files. This flexibility accommodates various user preferences for document submission. Upon uploading, "STEP 2: File Name" invites the user to provide a clear and descriptive name for the document, an

Figure C.18: *Stage 8*

	essential step for future reference and organization within the platform. Below these input areas, the interface lists the document details in a table. This includes the 'Operator', indicating the email of the user who uploaded the document, their 'Role', which aligns with their responsibilities within the asset management lifecycle, the 'File Name', the 'Date-Time' of the upload, and the 'Type' of the document. The user is then presented with 'Action' options—specifically, the ability to view or download the document, ensuring that all documents uploaded during the 'Strategic Definition' phase are manageable and accessible for the necessary personnel involved in the asset management process.

Figure C.19: *Stage 8*

9

```
if user is Registered Then
    user access Login
    if Login is True
        user Enter AIM-SYSTEM
        Check user Role
            if user Role is manager
                Give user managerPermissions
                While(user in specificProject)
                    user can view files
                    user can modify files
                    user can upload files
                    user can transfer files to BLOCK
                display mainDashboard
                    While(user in mainDashboard)
                        user can create new project
                        user can modify specific project
                        user can activate new user
            ElseIf user Role is supplier
                Give user supplierPermissions
                While(user in specificProject)
                    user can view files
                    user can upload files
                display mainDashboard
                    While(user in mainDashboard)
                        user can view project
            ElseIf user Role is contractor
                Give user contractorPermissions
                While(user in specificProject)
                    user can view files
                    user can upload files
```

Processing the data

The system described here is intricately designed to manage and secure documentation through a virtual environment that enhances project visualization with multi-format documentation and three-dimensional graphical models.

Upon verification of a user's registration and successful login, the system discerns the user's role—manager, supplier, contractor, consultant, or client—and assigns corresponding permissions. For example, a manager is endowed with comprehensive privileges within specific projects, such as viewing, modifying, and uploading files. Additionally, managers have the authority to transfer files onto the blockchain, reflecting the system's utilization of blockchain technology for secure document handling.

As the user engages with the main dashboard, tailored activities are enabled according to their role. Managers may create new projects and activate new user accounts, whereas suppliers and contractors are granted permissions relevant to their contribution to the project, like viewing and uploading project-specific files. Consultants have the ability to upload files, and clients can view and provide feedback on these files, ensuring a collaborative process throughout the asset's lifecycle.

In scenarios where a login attempt is unsuccessful, the system is programmed to guide the individual to a registration page for new users or to

Figure C.20: *Stage 9*

```
            display mainDashboard
                While(user in mainDashboard)
                    user can view project
        ElseIf user Role is consultant
            Give user consultantPermissions
            While(user in specificProject)
                user can view files
                user can upload files
            display mainDashboard
                While(user in mainDashboard)
                    user can view project
        Else Give user clientPermission
            While(user in specificProject)
                user can view files
                user can comment files
            display mainDashboard
                While(user in mainDashboard)
                    user can view project
ElseIf Login is False
    if user noRegister
        display registerPage
    ElseIf user noActive
        display noActive message
    Else display Login username or password falied
```

display a notification for inactive accounts or incorrect login credentials.

Crucially, when files are uploaded by authorized personnel, they are encrypted within the blockchain environment. These encrypted files are shared with the asset management team, allowing for secure and continuous management across the asset lifecycle. The system is built to prioritize security, as evidenced by the use of encrypted keys for file sharing, ensuring that data integrity and privacy are maintained at every stage.

Through this role-based access control system and its sophisticated use of blockchain technology, the platform assures that the asset management process is secure, efficient, and enhances the visual interpretation and understanding of the project for all stakeholders involved.

Figure C.21: *Stage 9*

Appendix D

BIM Global study

Country	BIM status	Main challenges, Risk or Barriers
United Kingdom	Mandated since 2016	• Lack of Standardisation. • Poor integrated with various parts. • Poor communication. • Uncertain cost for BIM model. • Different culture between stakeholders.
Saudi Arabia	Under consideration	• Misunderstanding of what is BIM. • Consolidate a standard between the consultants and contractors. • Resistance of change. • Contractor looks at BIM as additional cost. • Lack of BIM specialists in the region. • Lack of client demand. • Hardware and Software are expensive. • BIM introduced by developers. • Adopting with new technology.
Austria	Likely to be in place 2018	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Belgium	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Brazil	Road map under review	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Canada	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Chile	BIM mandated for 2020	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.

China	BIM required through the 12th national five-year plan	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Czech Republic	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Denmark	Requirement since 2007 adoption 2011	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
United Arab Emirates	Mandated for 2013	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance of change. • Contractor looks at BIM as additional cost. • Lack of BIM specialists in the region. • Lack of client demand. • Hardware and Software are expensive. • BIM introduced by developers. • Adopting with new technology.
Finland	Mandated for 2014	• Uncertain cost for BIM model. • Different culture between stakeholders.
France	Mandated for 2017	• Resistance to change. • Uncertain cost for BIM model. • Different culture between stakeholders.
Germany	Mandated from 2020	• Resistance to change. • Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Hong Kong	Mandated in place since 2014	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance of change. • Additional cost. • Lack of BIM specialists in the region. • Lack of client demand. • Hardware and Software are expensive. • BIM introduced by developers.
Ireland	Road map from 2018 to 2021	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Italy	Mandated for 2019	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Netherlands	No mandated	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.

New Zealand	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Norway	Mandated since 2016	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Portugal	No BIM requirement planned	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Qatar	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance of change. • Contractor looks at BIM as additional cost. • Lack of BIM specialists in the region. • Lack of client demand. • Hardware and Software are expensive. • BIM introduced by developers. • Adopting with new technology.
Singapore	Mandated in place since 2015	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Spain	Mandated for 2018	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Sweden	Mandated for Swedish transportation	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Switzerland	No regulation to date	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
USA	Multiple mandated	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.
Malaysia	Implemented in 2007	• Lack of competent staff to operate the software. • Lack of awareness of the technology. • Expensive software. • Longer time to develop the software
European Union	Mandated since 2014	• Uncertain cost for BIM model. • Different culture between stakeholders. • Resistance to change.

Table D.1: BIM global study

Appendix E

Research Ethics Approval

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

University of Nottingham Ningbo

Research Ethics Checklist for Staff and Research Students

[strongly informed by the ESRC (2012) Framework for Research Ethics]

A checklist should be completed for every research project or thesis where the research involves the participation of people, the use of secondary datasets or archives relating to people and/or access to field sites or animals. It will be used to identify whether a full application for ethics approval needs to be submitted.
You must not begin data collection or approach potential research participants until you have completed this form, received ethical clearance, and submitted this form for retention with the appropriate administrative staff.

The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

Completing the form includes providing brief details about yourself and the research in Sections 1 and 2 and ticking some boxes in Sections 3 and/or 4, 5, 6. **Ticking a shaded box in Sections 3, 4, 5 or 6 requires further action by the researcher**. Two things need to be stressed:

- Ticking one or more shaded boxes does not mean that you cannot conduct your research as currently anticipated; however, it does mean that further questions will need to be asked and addressed, further discussions will need to take place, and alternatives may need to be considered or additional actions undertaken.
- Avoiding the shaded boxes does not mean that ethical considerations can subsequently be 'forgotten'; on the contrary, research ethics - for everyone and in every project – should involve an ongoing process of reflection and debate.

The following checklist is a starting point for an ongoing process of reflection about the ethical issues concerning your study.

SECTION 1: THE RESEARCHER(S)

1.1: Name of principal researcher: Azzam Raslan

1.2: Status: ☐ Staff

☒ Postgraduate research student

1.3: School/Division: Architecture and Built Environment

1.4: Email address: raslan.azzam@nottingham.edu.cn

1.5: Names of other project members (if applicable):

1.6: Names of Supervisors (if applicable): Dr.Georgios Kapogiannis, Dr.Ali Cheshmehzangi, Dr. Walid Tizani, and Dr. Dave Towey

	Yes	No
1.7: I have read the University of Nottingham's Code of Research Conduct and Research Ethics (2010) and agree to abide by it: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx	☒	☐
1.8: (If applicable) I have read the University of Nottingham's e-Ethics@Nottingham: Ethical Issues in Digitally Based Research (2012) and agree to abide by it. http://www.nottingham.edu.cn/en/research/documents/e-ethics-at-the-university-of-nottingham.pdf	☒	☐
1.9: When conducting research on people (Section 5) I will prepare both a participant consent form as well as a *participant information sheet.* I am aware that the following templates are available on the Ethics webpage: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx • Participant consent form 1 • Participant Information Sheet English only	☒	☐

SECTION 2: THE RESEARCH

2.1: **Title of project:**

A conceptual framework to improve the operational process of an asset in the Kingdom of Saudi Arabia.

2.2: **Research question(s) or aim(s)**

1- Could Blockchain be the future facilitator of building information modelling management and asset information model?
2- What is the interrelation between BIM and Blockchain within the construction procurement processes?
3- How does a BIM collaborative culture and blockchain impact on the operation stage of an asset?

Aim

The aim of this present work is to investigate the adoption of Blockchain and BIM in the Saudi operational process of an asset. The scope of this research within the construction procurement processes focuses on the construction, hand over, and mainly on operation stage of a project lifecycle.

2.3: **Summary of method(s) of data collection**

This research will be fulfilled by using a qualitative case study, the case will be collected from the construction organisation to gaining the relevant subjective information. In addition, purposive sampling will be used to select participants for semi-structured interview and participatory observation. Data collection methods has been described along with the choice of multimethod approach of semi-structured interview and participatory observation have been discussed in relation to their philosophical position. The analysis of semi-structured interview and participatory observation will be carried out by making transcription of the recorded conversation.

2.4: **Proposed site(s) of data collection**

Location: The Kingdom of Saudi Arabia (KSA)

Project area: Makkah region, Jeddah city.

Company Name: Modern Cities Engineering Consultant **(MCEC)**

Place: (office/ site in use)

Project Name: Female Driving School at the University of King Abdul-Aziz **(KAAU)**

Procurement method: Design and Build.

Stage: in use, the project of this study is under the operation stage, so the researcher not required for a special clearing (training, safety assessment, and etc).

2.5: **How will access to participants and/or sites be gained?**

The researcher will take in consideration the ethical procedure in order to access for the participants (site/office). The research has been working on the Saudi construction industry, and there is a permission from a consultant Engineering company to conduct this pose work. In addition, the researcher will make a clear sheet for the research aim and objective to explain for the participant in details. Projects manager from construction companies, designers, consultant and suppliers will be the researcher target. Practically, Modern Cities Engineering Consultant (MCEC), has given the researcher an access for the data and to use their information in order to achieve this work. However, a pre-trip authorization will be asked, and relevant measures regarding insurance will be taken to protect the researcher.

SECTION 3: RESEARCH INVOLVING USE OF SECONDARY DATASETS OR ARCHIVES RELATING TO PEOPLE

If your research involves use of secondary datasets or archives relating to people all questions in Section 3 must be answered. If it does not, please tick the 'not relevant' box and go to Section 4.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
3.1: Is the risk of disclosure of the identity of individuals low or non-existent in the use of this secondary data or archive?	☐	☐
3.2: Have you complied with the data access requirements of the supplier (where relevant), including any provisions relating to presumed consent and potential risk of disclosure of sensitive information?	☐	☐

SECTION 4: RESEARCH INVOLVING ACCESS TO FIELD SITES AND ANIMALS

If your research involves access to field sites and/or animals all questions in Section 4 must be answered. If it does not, please tick the 'not relevant' box and go to Section 5.

NOT RELEVANT	☒

Please answer each question by ticking the appropriate box.

	Yes	No
4.1: Has access been granted to the site?	☐	☐
4.2: Does the site have an official protective designation of any kind?	☐	☐
If yes, have the user guidelines of the body managing the site a) been accessed?	☐	☐
b) been integrated into the research methodology?	☐	☐
4.3: Will this research place the site, its associated wildlife and other people using the site at any greater physical risks than are experienced during normal site usage?	☐	☐
4.4: Will this research involve the collection of any materials from the site?	☐	☐
4.5: Will this research expose the researcher(s) to any significant risk of physical or emotional harm?	☐	☐
4.6: Will the research involve vertebrate animals (fish, birds, reptiles, amphibians, mammals) or the common octopus (Octopus vulgaris) in any capacity?	☐	☐
If yes, will the research with vertebrates or octopi involve handling or interfering with the animal in any way or involve any activity that may cause pain, suffering, distress or lasting harm to the animal?	☐	☐

SECTION 5: RESEARCH INVOLVING THE PARTICIPATION OF PEOPLE

If your research involves the participation of people all questions in Section 4 must be answered.

Please answer each question by ticking the appropriate box.

A. General Issues

	Yes	No
5.1: Does the study involve participants age 16 or over who are unable to give informed consent? (e.g. people with cognitive impairment, learning disabilities, mental health conditions, physical or sensory impairments?	☐	☒
5.2: Does the research involve other vulnerable groups such as children (**aged under 16**) or those in unequal relationships with the researcher? (e.g. your own students)	☐	☒
5.3: Will this research require the cooperation of a gatekeeper* for initial access to the groups or individuals to be recruited?	☐	☒
5.4: Will this research involve discussion of sensitive topics (e.g. sexual activity, drug use, physical or mental health)?	☐	☒
5.5: Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	☒

5.6: Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	☒
5.7: Will this research involve people taking part in the study without their knowledge and consent at the time?	☐	☒
5.8: Does this research involve the internet or other visual/vocal methods where people may be identified?	☐	☒
5.9: Will this research involve access to personal information about identifiable individuals without their knowledge or consent?	☐	☒
5.10: Does the research involve recruiting members of the public as researchers (participant research)?	☐	☒
5.11: Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	☐	☒
5.12: Is there a possibility that the safety of **the researcher** may be in question?	☐	☒
5.13: Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	☒

**Gatekeeper- a person who controls or facilitates access to the participants*

B. Before starting data collection

	Yes	No
6.12: My full identity will be revealed to all research participants.	☒	☐
6.13: All participants will be given accurate information about the nature of the research and the purposes to which the data will be put. (*An example of a Participant Information Sheet is available for you to amend and use* at xxxxx) *http://www.nottingham.edu.cn/en/research/documents/participant-information-sheet-in-english-and-chinese.doc*	☒	☐
6.14: All participants will freely consent to take part, and, where appropriate, this will be confirmed by use of a consent form. (An example of a Consent Form is available for you to amend and use at: http://www.nottingham.edu.cn/en/research/researchethics/ethics-approval-process.aspx)	☒	☐
6.15: All participants will freely consent to take part, but due to the qualitative nature of the research a formal consent form is either not feasible or is undesirable and alternative means of recording consent are proposed.	☐	☒
6.16: A signed copy of the consent form or (where appropriate) an alternative record of evidence of consent will be held by the researcher.	☒	☐
6.17: It will be made clear that declining to participate will have no negative consequences for the individual.	☒	☐
6.18: Participants will be asked for permission for quotations (from data) to be used in research outputs where this is intended.	☒	☐

6.19: I will inform participants how long the data collected from them will be kept.	☒	☐
6.20: Incentives (other than basic expenses) will be offered to potential participants as an inducement to participate in the research. (Here any incentives include cash payments and non-cash items such as vouchers and book tokens.)	☐	☒
6.21: For research conducted within, or concerning, organisations (e.g. universities, schools, hospitals, care homes, etc) I will gain authorisation in advance from an appropriate committee or individual.	☒	☐

C. During the process of data collection

	Yes	No
6.25: I will provide participants with my University contact details, and those of my supervisor (*where applicable*) so that they may get in touch about any aspect of the research if they wish to do so.	☒	☐
6.26: Participants will be guaranteed anonymity only insofar as they do not disclose any illegal activities.	☒	☐
6.27: Anonymity will not be guaranteed where there is disclosure or evidence of significant harm, abuse, neglect or danger to participants or to others.	☒	☐
6.28: All participants will be free to withdraw from the study at any time, including withdrawing data following its collection.	☒	☐
6.29: Data collection will take place only in public and/or professional spaces (e.g. in a work setting	☒	☐
6.30: Research participants will be informed when observations and/or recording is taking place.	☒	☐
6.31: Participants will be treated with dignity and respect at all times.	☒	☐

D. After collection of data

	Yes	No
6.32: Where anonymity has been agreed with the participant, data will be anonymised as soon as possible after collection.	☒	☐
6.33: All data collected will be stored in accordance with the requirements of the University's Code of Research Conduct	☒	☐
6.34: Data will only be used for the purposes outlined within the participant information sheet and the agreed terms of consent.	☒	☐
6.35: Details which could identify individual participants will not be disclosed to anyone other than the researcher, their supervisor and (if necessary) the Research Ethics Panel and external examiners without participants' explicit consent.	☒	☐

E. After completion of research

	Yes	No
6.37: Participants will be given the opportunity to know about the overall research findings.	☒	☐

6.38: All hard copies of data collection tools and data which enable the identification of individual participants will be destroyed.	☒	☐

If you have not ticked any shaded boxes, please send the completed and signed form to the School's Research Ethics Officers, with any further required documents, for approval and record-keeping.

If you have ticked *any* shaded boxes **you will need to describe more fully how you plan to deal with the ethical issues raised by your research**. Issues to consider in preparing an ethics review are given below. Please send this completed form to the Research Ethics Officer who will decide whether your project requires further review by the UNNC Research Ethics Sub-Committee and/or whether further information needs to be provided.
Please note that it is your responsibility to follow the University's Research Code of Conduct and any relevant academic or professional guidelines in the conduct of your study. This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data. For guidance and UK regulations on the latter, please refer to the Data Protection Policy and Guidelines of the University of Nottingham:

Policy - http://www.nottingham.ac.uk/%7Ebrzdpa/local/dp-policy.doc

Guidelines -http://www.nottingham.ac.uk/~brzdpa/local/dp-guidance.doc

Any significant change in the project question(s), design or conduct over the course of the research should be notified to the School Research Ethics Officer and may require a new application for ethical approval.

Signature of Principal Researcher:

Signature of Supervisor (where appropriate):

Date 18-12-2019

Research Ethics Panel response

☑ the research can go ahead as planned

☐ further information is needed on the research protocol (see details below)

☐ amendments are requested to the research protocol (see details below)

School REO.. Date 29 December 2019

A. LIST OF POINTS TO CONSIDER WHEN SUBMITTING AN ETHICS REVIEW (taken from ESRC (2012) Framework for Research Ethics).

Risks

1. Have you considered risks to:
   - the research team?
   - the participants? Eg harm, deception, impact of outcomes
   - the data collected? Eg storage, considerations of privacy, quality
   - the research organisations, project partners and funders involved?
2. Might anyone else be put at risk as a consequence of this research?
3. What might these risks be?
4. How will you protect your data at the research site and away from the research site?
5. How can these risks be addressed?

Details and recruitment of participants

6. What types of people will be recruited? Eg students, children, people with learning disabilities, elderly?
7. How will the competence of participants to give informed consent be determined?
8. How, where, and by whom participants will be identified, approached, and recruited?
9. Will any unequal relationships exist between anyone involved in the recruitment and the potential participants?
10. Are there any benefits to participants?
11. Is there a need for participants to be de-briefed? By whom?

Research information

12. What information will participants be given about the research?
13. Who will benefit from this research?
14. Have you considered anonymity and confidentiality?
15. How will you store your collected data?
16. How will data be disposed of and after how long?
17. Are there any conflicts of interest in undertaking this research? Eg financial reward for outcomes etc.
18. Will you be collecting information through a third party?

Consent

19. Have you considered consent?
20. If using secondary data, does the consent from the primary data cover further analysis?
21. Can participants opt out?
22. Does your information sheet (or equivalent) contain all the information participants need?
23. If your research changes, how will consent be renegotiated?

Ethical procedures

24. Have you considered ethics within your plans for dissemination/impact?
25. Are there any additional issues that need to be considered? Eg local customs, local ‘gatekeepers’, political sensitivities
26. Have you considered the time you need to gain ethics approval?
27. How will the ethics aspects of the project be monitored throughout its course?
28. Is there an approved research ethics protocol that would be appropriate to use?

29. How will unforeseen or adverse events in the course of research be managed? Eg do you have procedures to deal with any disclosures from vulnerable participants?