CHAPTER 4

ANALYSIS AND RESULTS

4.1 Introduction

This chapter presents the analysis and results of the study, integrating both the qualitative and quantitative components of the research. The study used an exploratory sequential mixed-methods approach, first with qualitative interviews to gain in-depth insights from industry experts, followed by a quantitative survey to assess broader trends and validate emerging themes. The results are organized to address the study's research questions, highlighting key patterns, relationships, and implications for BIM adoption in Ghana's construction industry.

The first section presents findings from an exploratory qualitative study, which involved semi-structured interviews with industry stakeholders. The second section presents the quantitative survey results, which were designed based on insights from the literature and the qualitative phase. The survey gathered responses from a broader sample of construction professionals, allowing for statistical validation of key trends.

4.2 Qualitative Data Analysis

This section presents the analysis and results of the qualitative study conducted. The study was undertaken through one-on-one interviews, and the qualitative data collected were systematically analysed to explore the adoption of BIM in Ghana's construction industry. The analysis began with a thorough review of the interview transcripts, which allowed the researchers to familiarize themselves with the content and identify initial patterns and themes.

The analysis process employed NVivo qualitative data analysis software to code the data, adhering to the guidelines and examples outlined by Polkinghorne and Taylor (2022).

Subsequently, the researcher applied Clarke and Braun (2013) thematic analysis approach to pinpoint themes and sub-themes such as BIM awareness and knowledge, organizational and technological readiness for adoption, key drivers and challenges to BIM adoption and strategies for facilitating effective BIM adoption in the construction industry in Ghana. The analysis reveals patterns, similarities, and discrepancies in BIM adoption among Construction Industry stakeholders.

4.2.1 Respondents' profile

Table 4. 1 outlines the categorization and profile of interviewees included in the study. The study sample involved 21 stakeholders in the construction industry. The sample was selected by considering their relevance to the industry's decision-making and the priority of purpose. The sample consists of three categories of stakeholders: eleven (11) practising industry professionals, six (6) clients and four (4) government officials. The participants' diverse professional backgrounds allowed for collecting varied insights on the state of BIM adoption in Ghana.

The interview protocol focused on various aspects of BIM adoption within Ghana's construction industry. The study's findings are presented under the themes: BIM awareness and knowledge among stakeholders, challenges to BIM adoption in the industry and suggestions for effective BIM adoption.

Table 4. 1 Profile of interview participants

Participant ID	Categorization	Years of Experience	Current Role/Position
GO1	Government Official	7	Senior Policy Advisor
GO2	Government Official	8	Assist. Registrar/Project Coordinator
GO3	Government Official	15	Deputy Technical Director
GO4	Government Official	12	Urban Planning Officer
C1	Client	21	Facilities Manager
C2	Client	13	Snr. Project Manager
C3	Client	9	Dir. of Construction Procurement
C4	Client	15	Deputy Dir. of Physical Development
C5	Client	8	Project Manager
C6	Client	15	Dir. of Infrastructure
IE1	Industry Professional	14	Project Architect
IE2	Industry Professional	17	Electrical Engineer
IE3	Industry Professional	16	Dir. of Physical Development
IE4	Industry Professional	11	Project Manager/Contractor
IE5	Industry Professional	13	Principal Architect

Participant ID	Categorization	Years of Experience	Current Role/Position
IE6	Industry Professional	22	Project Coordinator
IE7	Industry Professional	19	Quantity Surveyor/Snr. Lecturer
IE8	Industry Professional	14	Lecturer/Architect
IE9	Industry Professional	15	BIM Coordinator
IE10	Industry Professional	12	BIM Technician
IE11	Industry Professional	16	Structural Engineer

4.2.2 BIM Awareness and Knowledge among industry stakeholders

The level of awareness and understanding of BIM remains a mixed bag among industry stakeholders in Ghana's construction industry. While many professionals have heard about BIM and are even using BIM tools, their knowledge about its application often stops at the surface and does not translate into a deep understanding or effective application. Participant IE1 captured this disparity, saying, *"There's generally a high level of awareness about the BIM platform and software…, but true knowledge and utilization of BIM within the industry are very low."* This sentiment suggests that while many professionals are aware of BIM software, there is inadequate knowledge to implement its extensive capabilities. Similarly, participant E10 noted, *"…the awareness of BIM is fairly widespread, but there's a significant gap in terms of practical understanding. Most of us know what BIM is in theory, but very few have the training or resources to implement it effectively."*

Many professionals view BIM primarily as a 3D modelling and visualization tool rather than a project management process. Participant IE2 explained that *"...while many professionals have heard of BIM, their understanding of its full potential and applications varies widely,"* with most focusing on its visual capabilities. Participant IE 5 added, *"...currently, the level of awareness is a bit high, but the knowledge of its application is now at the geometric level where BIM tools are used by most to translate a design into a 3D model for visualization purposes."* Participant IE11 stated, *".... most industry players view BIM simply as a design tool rather than a comprehensive process."* This narrow perspective restricts the potential benefits of BIM.

Larger firms, especially those involved in international projects, appear more familiar with BIM concepts. Participant IE7 stated, *"Smaller firms are still struggling with the basics…they don't fully understand how BIM can be applied beyond 3D modelling. Larger firms, especially those with international collaborations, tend to have a better grasp of BIM concepts."* Participant IE1 echoed this by pointing out, "*Foreign consultants I've worked with on projects are more familiar with and readily adopt BIM due to their structured and advanced construction industries."*

BIM awareness and knowledge remain concentrated in urban centres and among consultants, particularly architects. Participant IE7 observed, *"In my view, BIM awareness has seen some growth over the past few years, particularly among professionals in urban centres."* Architects tend to lead the way, as highlighted by *participant* E10: *"Architects tend to lead the way in BIM adoption mainly because they need to produce detailed visual representations."* While there is a growing awareness and some improvements in general knowledge, it is not evenly widespread among professionals and firms.

Among government officials, awareness of BIM is notably low. Participant GO3 explained, *"…awareness of BIM among government officials is relatively low, although it's improving."* Similarly, Participant GO2 remarked, *"...awareness of BIM is still at a basic level...it hasn't yet translated into widespread knowledge."*

This lack of familiarity among policymakers poses a significant challenge to driving industry-wide adoption. Without government leadership and advocacy, industry-wide adoption of BIM in Ghana will remain challenging.

There is varying BIM awareness and knowledge among the participating clients, with all respondents having at least heard about it. Some clients, such as Participant C1, demonstrate a general experience with BIM and recognize its value. As C1 noted: *"I am very familiar with BIM tools and their application in construction projects….it has proven invaluable for improving project visualization."* Yet, many clients remain on the peripheral, aware of the BIM but unsure of its practical applications. Participant C3 admitted: *"I'm aware of BIM, but I would not say I'm completely knowledgeable... I think BIM is becoming more popular in Ghana, but more education is needed for some of us."* Participant C4 echoed this sentiment: *"I've heard about BIM from some of the architects I work with... I still don't fully understand how it works in practice."*

Some clients noted that although they are familiar with BIM, they are yet to integrate it into their smaller projects. Participant C5 remarked, *"...in smaller projects, we tend not to use BIM, so my exposure is limited."* This perception was shared by Participant C4, who stated, *"I've seen some 3D models, but I don't have in-depth knowledge...it seems useful."* This highlights a broader challenge in promoting BIM adoption: while awareness grows, its practical application remains concentrated in more complex projects.

Consultants seem to play a critical role in bridging the knowledge gap for clients. Participant C2 shared, *"Most of my knowledge of BIM comes from consultants who have recommended its use..."* Participant C6 added, *"... I've been involved in projects where BIM was recommended by the consultants, but I don't have a deep understanding of it."* These insights underscore the important role of consultants as advocates for BIM.

The findings revealed that awareness of BIM among industry stakeholders in Ghana is relatively high, but this awareness does not always translate into deep knowledge or effective application. Almost all participants across different professional categories indicated that they were familiar with BIM in some form, yet the extent of this familiarity varied considerably. Many respondents admitted that while they have heard about BIM or encountered BIM tools in practice, their understanding of its broader process-oriented applications remains limited. This indicates that knowledge within the industry is still superficial and uneven.

A consistent theme across the responses was that many professionals perceive BIM primarily as a three-dimensional modeling and visualization tool rather than as an integrated project management process. This narrow perception was highlighted by several interviewees, who observed that most professionals stop at the visual and design functions of BIM without fully engaging with its potential for coordination, information sharing, and lifecycle management. As a result, BIM continues to be underutilized in ways that limit its transformative potential within the industry.

The analysis also highlighted clear differences between large and small firms in terms of BIM knowledge and adoption. Larger firms, particularly those engaged in international projects or collaborations, tended to demonstrate higher levels of familiarity with BIM concepts and applications. These firms have the resources and exposure necessary to experiment with or implement BIM processes more effectively. By contrast, smaller firms were found to be struggling with the basics, often only recognizing BIM software without fully applying it in their project workflows. This difference underscores the influence of global exposure, resources, and organizational capacity in shaping BIM adoption in Ghana.

Geography also played a role in shaping awareness levels. BIM knowledge was found to be concentrated in urban centres such as Accra, where professional networks are stronger and larger projects are more common. Professionals in rural areas demonstrated far less exposure to BIM and had limited opportunities to engage with it in practice. This geographical divide further illustrates how access to technology and knowledge resources determines the pace and extent of adoption.

Differences in awareness and knowledge were also apparent across professional groups. Architects were identified as leading the way in terms of BIM familiarity, largely because of their reliance on visual representation in design work. Engineers, especially those in structural and civil disciplines, demonstrated moderate awareness, while quantity surveyors, project managers, and contractors exhibited lower levels of understanding. This imbalance reflects the varying degrees to which BIM's current use aligns with the practical needs of different professions.

Among government officials and policymakers, awareness of BIM was found to be particularly low. Although some respondents acknowledged gradual improvement, most admitted that their familiarity remained basic. This poses a significant challenge because limited awareness within public institutions reduces the likelihood of BIM being promoted through national policies or regulations, thereby slowing down broader industry-wide adoption.

Clients also reported mixed levels of awareness and knowledge. All client participants confirmed that they had at least heard of BIM, but only a few expressed meaningful familiarities with its use in practice. While some clients acknowledged

BIM’s usefulness for visualization and communication, many remained uncertain about its practical application, particularly in smaller projects. In most cases, their exposure to BIM came indirectly through consultants, who introduced and recommended it during project planning stages.

The role of consultants therefore emerged as central in bridging the knowledge gap. Many clients attributed their understanding of BIM to consultants’ demonstrations and guidance rather than to their own internal capacity. Consultants acted as knowledge brokers, promoting BIM use on larger projects and serving as intermediaries between clients and the technology. However, this reliance on consultants also highlighted clients’ limited ability to independently drive BIM integration into their projects.

4.2.3 Readiness of Ghana's Construction Industry Towards BIM Adoption

The construction industry exhibits a range of readiness for BIM adoption, largely shaped by the availability of resources, the attitude of leadership and various systemic challenges that impede the industry's collective advancement towards technology adoption.

Participants consistently highlighted the hesitance of senior management to invest in BIM technologies and processes. Participant IE9 observed that *"Leadership buy-in is still lacking across many firms…with top management reluctant to invest in new technologies,"* an opinion that participant IE5 also expressed, noting that *"Currently, leadership buy-in is low."* Such reluctance on the part of organizational management can be attributed to a lack of familiarity with the benefits of BIM and its potential financial implications. As noted by participant IE7, *"Leadership needs to embrace BIM fully and understand its strategic value."* Without a commitment from decision-makers, the readiness levels tend to stagnate, as investments in technology, training, and infrastructure are frequently not prioritized. Participant GO2 pointed out, *"Most decision-makers have heard of BIM, but only a few fully grasp its capabilities."* A lack of understanding hinders the ability to make well-informed decisions and delays the adoption of strategies that could promote the widespread adoption of BIM across the industry.

The distinction between larger and smaller local firms further underscores the differences in BIM preparedness. Smaller firms encounter considerable challenges due to financial limitations and technological deficits. Participant IE3 noted, *" Smaller firms often don't have the resources to implement BIM fully, both in terms of technology and training."* In a related context, participant GO4 stated that *"larger firms, especially those involved in international projects, are often better prepared as they regularly need to utilize BIM to meet client expectations."*

The expenses associated with software and hardware present significant challenges, as highlighted by participant IE9: *"... the cost of software is a big barrier, especially for smaller firms. They can't afford to invest in the necessary infrastructure."* They lack the financial resources to invest in the essential infrastructure. Small firms' financial constraints hinder their capacity to invest in BIM, intensifying the technological divide and forcing them to depend on outdated systems that are inadequate for supporting BIM processes. Participant IE8 emphasized this issue, noting, "There'*s still a lot of progress to be made. Many firms are operating with outdated technology that struggles to run BIM software effectively."* Additionally, participant IE 4 pointed out that the use of rudimentary equipment, such as low-performance laptops and desktops, noting that *"…most firms use basic computers like laptops and desktops which lack the capacity to handle advanced BIM tools and related technologies such as VR and AR."*

Another challenge to the readiness for BIM adoption is the disjointed project management culture that characterizes the construction industry in Ghana. Participant IE10 stated, *"The fragmented project management culture…where everyone works independently makes it hard to introduce collaborative BIM workflows."* The nature of this approach to project delivery constrains the collaborative capabilities of BIM, which fundamentally relies on the sharing of data and the integration of decision-making processes. Participant IE7 proposed an essential cultural transformation: *"Firms should move away from siloed project management approaches and foster a culture of collaboration with information sharing and joint decision-making."* A shift of this nature requires intended effort and dedication from all stakeholders in the industry to foster a culture of trust and collaboration.

The widespread shortcomings in technological infrastructure pose a considerable challenge to implementing BIM. Participant IE10 notes, *"Most firms* *in Ghana don't have the technological infrastructure needed for full-scale BIM adoption."* Regional disparities further complicate the issue; participant IE3 noted, *"The technological infrastructure needed for full BIM adoption is still lacking in many parts of the country."* Similarly, Participant GO4 opined that *"The industry is not yet fully equipped…access to high-quality computers, reliable internet, and up-to-date BIM software is still a challenge for many firms"* Many firms are still encountering difficulties in securing high-end computers, dependable internet connectivity, and the most up-to-date BIM software. The challenges faced are particularly evident in regions with limited internet connectivity. As highlighted by Participant C3, *"the lack of stable internet connectivity in certain regions poses a major challenge to cloud-based BIM."* The lack of adequate infrastructure slows the adoption process and deepens the gap between firms with access to current technologies and those without them. This technological deficiency is compounded by inadequate internet infrastructure, vital for cloud-based BIM activities. Participant IE2 emphasized that "*inconsistent internet services and inadequate data management infrastructure often hinder effective BIM adoption."*

The necessary measures to enhance readiness are acknowledged in light of these challenges. The participants consistently recognized that training, resource allocation, and infrastructure upgrades are fundamental components. Participant IE9 highlighted the necessity of a phased strategy, stating, *"We need time to train professionals, upgrade infrastructure, and ensure that smaller firms aren't left behind"* This acknowledgement demonstrates a shared understanding of the industry's potential for advancement, provided the appropriate interventions are made.

The readiness of Ghana's construction industry towards BIM adoption emerged as varied and uneven, largely shaped by organizational leadership attitudes, financial capacity, technological infrastructure, and entrenched project management practices. A recurring concern raised by participants was the reluctance of senior management to commit resources to BIM adoption. While many top executives and decision-makers in firms are aware of BIM in general terms, few fully understand its strategic benefits, leading to hesitation in investing in software, training, or supporting infrastructure. This leadership gap acts as a major bottleneck, as firms without committed top-level support are unable to prioritize BIM adoption and instead continue to rely on traditional project management systems. The findings clearly suggest that the buy-in of organizational leadership is a crucial determinant of readiness, and without this commitment, progress remains slow and fragmented.

The analysis further highlighted significant differences in readiness between larger firms and smaller, locally based companies. Larger firms, particularly those engaged in international projects or collaborations, showed greater preparedness, partly because they are compelled to meet international client demands where BIM is already established as a requirement. These firms often had stronger financial bases and better access to technological tools, making them better positioned to invest in BIM infrastructure. Conversely, smaller firms struggled due to limited financial resources, inadequate technological infrastructure, and low exposure to BIM processes. Many small firms reported relying on outdated software and low-capacity equipment, such as basic laptops and desktop computers, which are insufficient for handling advanced BIM applications. This divide demonstrates that organizational size and access to resources play a decisive role in shaping BIM readiness, leaving many small and medium firms at a disadvantage.

The cost of software and hardware also stood out as a major barrier across the industry. Participants noted that BIM software licenses, compatible high-performance computers, and related technologies such as Virtual Reality (VR) or Augmented Reality (AR) tools remain financially out of reach for many firms. For smaller organizations, these costs are prohibitive, forcing them to rely on rudimentary tools that undermine their ability to adopt BIM. Moreover, outdated infrastructure in many firms means that even when software is available, the supporting hardware often cannot run it effectively. This technological deficiency is compounded by the broader challenge of internet reliability, as many regions in Ghana continue to experience inconsistent or poor connectivity. Since BIM increasingly depends on cloud-based collaboration and real-time data sharing, weak internet infrastructure severely undermines the ability of firms to participate in collaborative workflows. The findings therefore reveal a dual barrier of inadequate hardware and insufficient internet services, both of which slow down readiness.

Beyond resource limitations, the cultural context of project management in Ghana also emerged as a significant obstacle to BIM adoption. The industry remains highly fragmented, with firms and professionals often working independently rather than collaboratively. This siloed culture is fundamentally at odds with BIM, which requires integration, data sharing, and collective decision-making across different disciplines. Participants emphasized that without a cultural shift toward collaboration, the industry will continue to face challenges in embedding BIM workflows into practice. A transformation toward joint planning, trust, and open communication is essential to unlock the collaborative advantages of BIM, but such a shift requires conscious effort and leadership across all levels of the industry.

Despite these challenges, there was a general acknowledgment among participants that readiness can be improved with deliberate interventions. Training was highlighted as a key strategy, with the recognition that professionals need continuous upskilling to keep pace with BIM developments. Resource allocation and infrastructure upgrades were also viewed as essential to narrow the gap between firms with advanced capabilities and those still struggling with outdated systems. Many respondents supported a phased implementation approach, where investments in training, infrastructure, and technology upgrades are rolled out systematically to ensure inclusivity. Such a gradual strategy would allow smaller firms to catch up while reducing the risk of deepening inequalities in adoption levels.

4.2.4 Drivers of BIM Adoption

Several factors were identified as influencing participants' limited adoption of BIM in their project workflows. Participants believed BIM's ability to improve stakeholder collaboration was a key reason for its adoption. Industry professionals emphasized how BIM enhances communication and ensures project participants remain aligned when working on a project. Participant IE4 noted that *"The use of BIM has improved collaboration between architects, engineers, and contractors,"* while participant IE8 pointed out that *"the ability of BIM to enhance project coordination and visualization helps in reducing misunderstandings."* This collaborative approach significantly reduces errors, lessens the necessity for rework, and improves overall efficiency.

The ability of BIM to produce 3D models and detailed visualizations was mentioned as a significant benefit for clients, who usually request its use. Participant C1 highlighted this: *"BIM allows the consultants to create 3D models that provide a clear visual representation of the project…."* Participant C3 also noted: *"The ability to visualize the project in 3D is very helpful for us….it reduces the number of surprises during construction."* The improved visualization helps clients who may not have technical backgrounds better understand project designs and make more informed decisions.

The influence of international collaboration on projects played a significant role in compelling professionals to adopt BIM. This trend highlights the desire of Ghanaian firms to adopt this technology to remain competitive. Participant G3 observed, *"Firms involved in international projects often find it essential to utilize BIM,"* participant G4 pointed out that *"the worldwide demand for BIM is driving Ghanaian construction firms to adopt its use."* In a related context, participant C3 noted, *"Firms are embracing BIM to align with international standards and maintain their competitiveness in global markets."* These findings suggest that engagement with international consultants and clients helps weave BIM requirements into local practices, thus compelling local firms to innovate and ultimately speed up their BIM adoption process. Participant IE10 highlighted the importance of *"Collaboration with foreign firms that use BIM on international projects."* Participant IE9 further underscored this observation, noting, *"International clients are increasingly demanding the use of BIM, which pushes local firms to adopt the technology."*

The ability of BIM to improve project management efficiency and reduce costs is a compelling reason for its adoption. Participant IE7 highlighted that he started using BIM because of "*…the need for better project management and the desire to minimize errors during construction."* This viewpoint is shared by participant E8, who stated, *"Organizations are mainly driven by the need to improve project coordination and reduce costly errors."*

The growing need for sustainable and energy-efficient buildings appears to drive adoption as BIM's capabilities in energy modelling and the efficient use of materials are becoming essential elements in the construction industry. Participant IE8 commented, *"The rising demand for environmentally friendly and energy-efficient buildings is also a key factor."* BIM helps firms meet their sustainability goals by integrating these features, aligning with current global trends and promoting more environmentally friendly construction practices.

Client involvement, whether from private or government entities, is vital in promoting the adoption of BIM. Participant IE5 observed that *"...basically, client requirement seems to be a major factor…when both private and public organizations required that their projects be delivered in BIM, especially for the visualization."* External pressure motivates firms, prompting them to invest in BIM and align their operational processes with other project participants' expectations. Participant IE6 also highlighted this dynamic, noting that *"BIM gives us a competitive advantage by improving collaboration and reducing errors."* This highlights how client-driven demand can be a powerful catalyst for widespread adoption across the industry.

The findings reveal various factors that promote the adoption of BIM in Ghana's construction sector, including technical, economic, and market-oriented aspects. BIM's ability to enhance collaboration, streamline project management processes, and support sustainability goals has made it a vital component of modern construction practices. The influence of international standards and client expectations underscores the importance of aligning local practices with global benchmarks.

To maximise the most of these enablers, the industry must focus on raising awareness about the benefits of BIM among stakeholders and providing targeted training to address existing knowledge gaps. Collaboration between local and international firms could significantly boost the adoption of advanced practices within Ghanaian firms.

The findings revealed several interrelated drivers that are gradually shaping the adoption of BIM in Ghana's construction industry. A dominant theme emerging from the interviews was BIM's ability to foster collaboration among diverse project stakeholders. Professionals emphasized that BIM provides a common platform for architects, engineers, contractors, and clients to communicate more effectively, reducing misunderstandings and ensuring greater alignment throughout the project lifecycle. This collaborative function not only reduces costly errors and the need for rework but also improves efficiency and trust among team members. Such attributes make BIM a powerful driver of adoption, especially in contexts where miscommunication and design discrepancies are common challenges.

Another strong motivator for BIM adoption is its advanced visualization capability. Many participants highlighted that BIM's ability to generate detailed 3D models helps bridge the gap between technical professionals and non-technical clients. Clients, in particular, find BIM valuable because it enables them to clearly visualize designs and anticipate potential issues before construction begins. This not only builds client confidence but also facilitates informed decision-making, thereby strengthening BIM's role as a client-oriented driver of adoption. The capacity to deliver clarity in visualization also helps reduce disputes and fosters smoother project execution.

International collaboration and global competitiveness also emerged as significant forces pushing BIM adoption in Ghana. Firms engaged in projects with international consultants or clients are increasingly compelled to adopt BIM, as it has become a requirement in global markets. Engagement with international partners often exposes local firms to advanced standards, practices, and tools, creating both a learning opportunity and a competitive necessity. This external pressure is particularly influential in accelerating adoption, as Ghanaian firms seek to remain relevant, secure contracts, and align with global industry expectations. As participants noted, the requirements of foreign clients and the influence of multinational collaborations play a decisive role in compelling local firms to integrate BIM into their workflows.

In addition, the efficiency gains associated with BIM provide another compelling incentive for adoption. Participants underscored how BIM supports improved project management by enhancing coordination, reducing errors, and minimizing construction delays and associated costs. The ability to streamline workflows and avoid costly rework directly appeals to firms seeking to improve profitability and meet deadlines. This efficiency-driven motivation is especially important in a sector where financial constraints and resource wastage often undermine project performance.

Sustainability goals are also becoming an emerging driver of BIM adoption. With increasing global and local interest in environmentally friendly and energy-efficient buildings, BIM's tools for energy modeling, material optimization, and sustainable design are highly valued. Participants acknowledged that BIM enables firms to align with broader environmental trends, meet regulatory expectations, and respond to client demands for greener projects. This sustainability dimension positions BIM not only as a technological solution but also as a strategic approach that connects construction practice with environmental responsibility.

Clients, both private and public, were identified as pivotal actors in driving adoption. Their explicit requirements for BIM-based project delivery often force firms to adapt in order to secure contracts and remain competitive. This dynamic shows how external demand acts as a powerful catalyst, compelling firms to restructure workflows and invest in technology despite initial resistance or resource limitations. When clients recognize the value of BIM in improving visualization and reducing errors, they effectively create industry-wide momentum toward adoption.

Taken together, the drivers of BIM adoption in Ghana can be categorized into technical, economic, and market-oriented dimensions. Technically, BIM offers collaboration, visualization, and sustainability benefits. Economically, it delivers efficiency, cost reduction, and improved project management. Market-wise, international collaboration and client requirements exert strong external pressure that compels adoption. These findings underscore the importance of both internal efficiency drivers and external market forces in shaping BIM adoption patterns in Ghana. For adoption to accelerate further, industry stakeholders must amplify awareness of BIM's benefits, strengthen training to bridge existing knowledge gaps, and foster deeper collaborations with international firms. By leveraging these drivers strategically, Ghana's construction industry can align more effectively with global best practices while addressing local development needs.

4.2.5 Challenges of BIM Adoption

The costs associated with setting up BIM emerged as a common theme among all participant groups. Industry professionals frequently emphasize the considerable cost of software licenses and the required hardware as a substantial barrier to adoption. As participant IE1 pointed out, *"The main issue is that BIM is an expensive platform...most of the BIM software used locally is pirated, but to immerse in BIM fully, you need to pay for an annual subscription."* This viewpoint was echoed by participant IE7, who noted, *"The initial investment in software licenses and training can be steep,"* and participant GO3 acknowledged the considerable challenge presented by *"...the high upfront cost of software licenses and hardware upgrades is a major obstacle."* The financial barrier poses a considerable challenge for individuals and smaller firms with inadequate resources, intensifying the existing inequalities in their access to technological resources and industry innovation opportunities. Participant C4 noted: *"The cost of implementing BIM is high... smaller firms struggle to justify the expense.* The high software cost, licenses, and training can be prohibitive for smaller firms, limiting their ability to adopt BIM.

The lack of trained BIM professionals and inadequate skill development initiatives emerged strongly. Industry experts have raised concerns about the scarcity of local BIM expertise, with participant IE11 highlighting, *"...there are not enough skilled professionals who understand BIM."* In a related context, participant IE8 stated, *"There aren't enough training programs, and many firms don't have access to the skilled professionals needed."* These comments reveal a notable shortcoming in capacity building, a crucial element for enabling the successful adoption of BIM. Participant C6 pointed out the notable skill gap by remarking, *"...the lack of formal BIM training programs in Ghana is a major obstacle to widespread adoption."*

Another major obstacle is the resistance to change; it reflects a broader hesitance within the industry to move away from traditional methods. Industry experts, such as those from Participant IE11, have observed, "*There's also a resistance to change in the industry, with many professionals sticking to traditional methods because they find them more comfortable."*. Many professionals stick with traditional methods, finding comfort in their familiarity. Participant IE3 explained: *"The resistance to change is a big issue… some professionals are stuck in their ways and prefer traditional 2D drawings."* Participant C5 added: *"...not everyone is comfortable with technology, especially the older generation…"* This cultural resistance to adopting new technologies and workflows slows down the transition to BIM in many organizations. Successful BIM adoption requires more than just technological investment; it also demands a shift in the organizational mindset.

The lack of a unified national strategy and standards for implementing BIM deepens these challenges. Participant IE8 pointed out, *"The lack of a government mandate for BIM in public projects has slowed its adoption across the industry."* Participant GO4 acknowledged this shortcoming: *"International partnerships often drive the discussions around BIM, but there's no coordinated national strategy."* Without clear government policies and incentives, stakeholders frequently hesitate to prioritize the adoption of BIM. Several clients identified the lack of industry-wide BIM standards as a significant challenge. C4 mentioned: *"The biggest challenge for me is the lack of standards. Every consultant seems to use a different BIM software."* C6 echoed this concern: *"The lack of standards is a major issue."* Without standardized protocols, ensuring compatibility between different software platforms and maintaining consistency across projects becomes difficult, creating barriers to unified BIM adoption. Participant IE10 rightly added, *"Government policies currently have a minimal impact on BIM adoption."*

A unique challenge related to BIM's legal and contractual arrangement was observed. Participant C1 believed that *"BIM introduces new legal and contractual complexities concerning data ownership, intellectual property, and responsibilities..."* This suggests that transitioning to BIM requires not just technical and financial readiness but also a reassessment of existing contractual frameworks to foster the collaborative nature inherent in the technology. These complexities, compounded by the absence of clear regulations in Ghana, further complicate the widespread adoption of BIM.

The results reveal that the challenges of BIM adoption in Ghana's construction industry are deeply multifaceted, spanning financial, technical, organizational, and regulatory domains. Foremost among these is the prohibitive cost of acquiring and maintaining BIM systems. Participants consistently stressed that the high cost of software licenses, hardware upgrades, and continuous subscriptions presents a major barrier, particularly for smaller firms and individual professionals. Many admitted resorting to pirated versions of BIM software as a survival strategy, reflecting the disconnect between financial capacity and technological aspirations. The high upfront investment not only intensifies inequalities in access to innovation but also discourages firms from fully embracing BIM as an integrated process. Smaller firms, in particular, find it difficult to justify such costs when operating within already tight budgets and competitive market conditions.

Equally significant is the widespread shortage of trained BIM professionals and the limited availability of structured training opportunities. Several participants pointed out that Ghana lacks a sufficient pool of experts capable of implementing BIM at scale. This shortage creates a vicious cycle: firms hesitate to invest in BIM because they cannot find the right expertise, while individuals are discouraged from pursuing training because of limited institutional support. The lack of formal, accessible, and affordable training programs deepens the knowledge gap and leaves many professionals with only superficial awareness of BIM tools rather than practical, hands-on competence. The findings suggest that without deliberate capacity-building initiatives, the workforce will remain unprepared to support BIM adoption, regardless of financial or technical readiness.

Resistance to change emerged as another fundamental barrier. Many professionals, particularly those with decades of experience in traditional 2D-based workflows, are hesitant to adopt BIM due to the cultural comfort of established practices. This reluctance often manifests as skepticism, inertia, or outright rejection of new digital processes. Participants emphasized that professionals in the older generation especially find it difficult to transition to digital tools, preferring manual methods they consider more reliable. Such resistance indicates that BIM adoption is not solely a technical or financial issue but also a cultural and organizational one. Overcoming this barrier requires deliberate change management strategies, including leadership advocacy, awareness campaigns, and incremental integration of BIM to reduce perceived disruption.

At the policy level, the absence of a national strategy and formal standards presents a structural challenge to BIM adoption. Participants repeatedly highlighted the lack of government mandates requiring BIM use in public projects, which has slowed momentum across the industry. Unlike in other jurisdictions where BIM adoption has been accelerated by government regulations and standardized guidelines, Ghana’s industry remains fragmented, with each consultant or firm often relying on different software or approaches. This lack of standardization creates compatibility problems, undermines collaboration, and discourages investment in training or software acquisition. Without a coordinated national framework, stakeholders remain uncertain about the long-term trajectory of BIM in Ghana, leading to inconsistent and fragmented adoption efforts.

Beyond technical and regulatory issues, participants also pointed to legal and contractual complexities introduced by BIM. Concerns around data ownership, intellectual property, liability, and responsibilities within BIM-based projects emerged as unique barriers. The collaborative nature of BIM blurs traditional lines of responsibility in construction contracts, raising questions about who owns the model, who is liable for errors, and how intellectual property should be protected. In Ghana, the absence of updated legal and regulatory frameworks to address these questions adds another layer of hesitation for firms and clients considering BIM. Without clear guidelines, the legal risks may outweigh the perceived benefits, slowing down its adoption.

Taken together, the findings underscore that the challenges of BIM adoption in Ghana are not isolated but interconnected, amplifying one another in ways that hinder progress. Financial barriers limit investment in training; skill shortages reduce confidence in adoption; cultural resistance slows organizational change; and the absence of national standards prevents a unified approach to implementation. Additionally, unresolved legal and contractual concerns exacerbate uncertainty.

Addressing these multifaceted challenges requires a concerted, collaborative approach among policymakers, industry leaders, and academic institutions. Financial support mechanisms, structured training programs, government-led standards, and legal reforms are necessary to create an enabling environment where BIM can thrive. Without such interventions, BIM adoption in Ghana risks remaining fragmented and superficial, with only larger firms and international collaborations realizing its full benefits.

4.2.6 Impact of BIM Adoption on Project Outcomes

Participants acknowledged BIM's potential to improve communication, coordination, cost efficiency, time savings, and overall project outcomes. However, they also emphasize that limited adoption has restricted the technology's full benefits, particularly among smaller firms and locally driven projects.

A recurring theme across all stakeholder groups is BIM's ability to enhance coordination and communication among project teams, leading to more efficient project execution. Experts note that BIM offers an integrated approach by enabling architects, engineers, and contractors to collaborate more effectively. As participant IE4 states, *"BIM has improved communication and coordination among our project stakeholders."* This view is echoed by participant IE3, who remarks that, *"We've seen noticeable improvements in communication and efficiency."* Respondents also highlight how BIM has positively transformed their project coordination by reducing misunderstandings and fostering real-time collaboration. Participant C3 observes that *"BIM has significantly improved coordination and collaboration among stakeholders, leading to fewer errors."* This view is echoed by participant C1, who emphasizes that *"the ability to collaborate in real time through BIM has helped reduce project delays and misunderstandings."* By centralizing project information and ensuring real-time updates, BIM minimizes miscommunication, enhances decision-making, and improves workflow efficiency.

Another widely recognized benefit of BIM adoption is its ability to identify design conflicts early in the project lifecycle, thereby reducing rework and associated delays. Experts highlight that BIM helps construction teams identify potential issues before they escalate, leading to significant time savings. Participant IE5 explains, *"Using BIM, we've reduced rework and saved significant time by detecting design conflicts early."* Government officials support this view, emphasizing the role of BIM in reducing project timelines. Participant GO2 notes that *"BIM has significantly impacted our construction project outcomes…it has reduced timelines and enabled better planning."* Clients also acknowledge that BIM helps minimize errors that would otherwise cause delays and disruptions.

Participant C1 states, *“BIM has greatly improved how construction projects are performed... It helps detect errors early on, saving costs.”* By ensuring that construction teams can anticipate and resolve potential issues before they arise, BIM helps ensure that projects are completed on time, which is a critical factor in maintaining project budgets and client satisfaction.

Cost efficiency is another area where BIM has had a tangible impact on project performance, as highlighted by stakeholders. Experts note that by improving project visualization and facilitating better planning, BIM has helped avoid costly errors and improve material use. Participant IE3 explains that *“BIM has greatly improved project visualization and planning. The ability to detect clashes early on has saved time and reduced cost overruns.”* Similarly, participant IE7 emphasizes the financial benefits, stating that *“On the financial side, accurate cost estimation and material optimization have cut costs considerably.”* By providing detailed insights into project requirements and potential risks, BIM enables more effective budgeting and resource management, further enhancing overall project performance. Respondents also emphasize how BIM’s streamlined workflows help achieve cost efficiency. Participant C2 remarks that *“the introduction of BIM has led to noticeable improvements in project delivery,”* highlighting how cost savings extend beyond the planning phase into actual construction.

While BIM adoption in Ghana remains limited, stakeholders recognize its potential to support sustainability in construction projects. Experts highlight that BIM enables precise energy modelling and resource efficiency, which are crucial for sustainable building practices. E10 states that *“BIM supports sustainable practices by optimizing resource use, which is particularly important for large projects.”* E8 further adds that *“For sustainability, it enables better analysis of building performance.”* These sustainability benefits, although not yet fully realized due to limited adoption, demonstrate BIM’s potential to transform the construction industry in terms of eco-friendly practices and long-term project performance.

Despite BIM’s clear benefits, stakeholders unanimously agree that its impact on construction project performance in Ghana remains limited due to low adoption rates. Experts acknowledge that BIM has the potential to significantly improve project outcomes; however, its benefits are not yet widely felt. E7 remarks, *"BIM has the potential to drastically improve project outcomes, but its impact has not been fully realized in most projects due to limited adoption."*

Government officials reinforce this concern, noting that smaller firms struggle with adoption due to financial constraints, lack of government mandates, and insufficient technical knowledge. GO3 states, *"BIM is seen as a tool that can help streamline processes and improve project outcomes, but its impact is limited by low adoption rates."* This observation aligns with experts' views that the benefits of BIM have primarily been realized in high-profile projects, while smaller firms and local contractors lag in adoption. E10 highlights that *"So far, the impact of BIM has been limited to a few high-profile projects."*

Most respondents acknowledged this challenge, with many noting that while BIM adoption has yielded significant improvements when implemented, it is still not the industry norm. As BIM adoption increases, stakeholders anticipate that its positive impact on project performance will become more widespread across the industry.

The findings reveal that BIM adoption has the potential to transform project outcomes in Ghana's construction industry, particularly in areas such as communication, coordination, cost efficiency, time savings, and sustainability. However, participants emphasized that these benefits are still unevenly distributed due to the limited extent of BIM use, especially among smaller firms and locally managed projects. While large, high-profile projects and firms with international collaborations have begun to realize these advantages, the broader industry has yet to fully harness BIM's capabilities.

One of the most widely acknowledged impacts of BIM is its ability to enhance communication and coordination among project stakeholders. Participants consistently noted that BIM centralizes project data, allowing architects, engineers, and contractors to collaborate in real time. This shared platform helps reduce misunderstandings, improve transparency, and foster smoother workflows. Respondents reported that BIM-driven collaboration significantly reduces errors and delays, ultimately leading to more efficient project delivery. For many professionals, the capacity to work from a single, integrated model ensures that all parties remain aligned throughout the project lifecycle. This improved coordination strengthens trust among stakeholders and enhances the overall quality of project outcomes.

BIM's ability to detect design conflicts early in the project lifecycle was highlighted as another critical contributor to improved outcomes. By identifying clashes at the planning stage, BIM helps minimize rework, prevent costly disruptions, and reduce project delays. Participants explained that early conflict detection not only saves time but also enhances predictability in project execution. Government officials in particular noted that BIM adoption has shortened project timelines and enabled more effective planning. Clients echoed this benefit, noting that BIM reduces the risk of surprises during construction and increases satisfaction with the final product. The ability to anticipate challenges before construction begins strengthens confidence in project delivery and ensures greater alignment with client expectations.

Cost efficiency also emerged as a central outcome of BIM adoption. Respondents emphasized that BIM supports accurate cost estimation, optimized resource allocation, and minimized material waste. These benefits translate into significant savings for both contractors and clients. Several participants highlighted how the use of BIM improves project visualization, enabling construction teams to anticipate and prevent errors that would otherwise lead to cost overruns. The financial advantages extend beyond the planning stage into actual construction, where streamlined workflows and improved coordination help projects stay within budget. For firms operating in an increasingly competitive market, the cost-efficiency benefits of BIM provide both operational and strategic value.

Another notable impact of BIM, though still underdeveloped in Ghana, is its contribution to sustainable construction. Participants observed that BIM's advanced features allow for energy modeling, resource efficiency, and performance analysis, all of which support environmentally friendly practices. While these sustainability benefits are not yet widespread, due to limited adoption, they represent an important area where BIM could contribute to global environmental goals. Stakeholders noted that the rising demand for sustainable and energy-efficient buildings makes BIM particularly relevant for the future of Ghana's construction industry. By integrating

BIM into design and project delivery, firms can align with international sustainability standards and meet growing client demand for eco-friendly construction.

Despite these benefits, respondents unanimously agreed that BIM's overall impact on project outcomes in Ghana remains limited by low adoption levels. Experts explained that while BIM adoption has brought measurable improvements in projects where it has been implemented, such cases are not representative of the broader industry. Government officials echoed this concern, pointing out that smaller firms face significant barriers such as high costs, lack of technical knowledge, and absence of regulatory mandates. As a result, BIM's transformative potential has so far been realized primarily in large, high-profile projects, often involving international clients or consultants.

4.2.7 Strategies for Effectively Implementing BIM

The strategies emphasize the significance of government leadership, highlight the critical role of education and training, advocate for the provision of financial incentives, and underscore the necessity of establishing national BIM standards. Together, they provide a structure for addressing the deep-rooted challenges that have hindered widespread adoption.

All respondents consistently emphasize the crucial role of government in spearheading the adoption of BIM. A considerable number of participants noted that without clear government directives and policy frameworks, we can expect ongoing inconsistencies and a slow progression in the adoption of BIM. Participant GO3 states, *"Without a clear government directive or policy framework supporting BIM, its adoption within government-led projects remains slow."* Experts in the field have shared comparable perspectives, with participant IE11 stating, *"If the government mandated BIM for public projects, it would drive industry-wide adoption."* The necessity for BIM use in public sector projects has emerged as a crucial driver for its extensive adoption. Participants G2 and G3 noted that these mandates could require firms to integrate BIM into their operational processes, particularly regarding large-scale infrastructure projects. In a related context, clients like participant C3 highlighted, *"If the government were to introduce policies requiring BIM for certain projects, particularly large-scale infrastructure projects,* *we'd likely see a quicker uptake."* These mandates aim to establish a benchmark for the private sector's integration of BIM, while simultaneously fostering consistency in its application across the industry.

An essential strategy involves improving educational and training programs to cultivate the requisite skills for the effective use of BIM. Many participants strongly supported integrating BIM into academic curricula, emphasizing the importance of effectively preparing the next generation of professionals. Participant IE7 emphasized, *"Including BIM in the curriculum at universities would help prepare the next generation of professionals for BIM,"* while participant GO1 suggested, *"universities and professional bodies should offer more BIM-focused educational programs."* Beyond formal education, specialised training programs, workshops, and seminars play a significant role in enhancing the skills of existing professionals. Participant GO4 highlighted the importance of "*implementing more focused awareness campaigns and training sessions specifically designed for policymakers,"* while Participant IE11 underscored that *"...for BIM to be effectively adopted, there needs to be more government and industry support, including training programs and subsidies for smaller firms."* Clients recognized the significance of ongoing professional development, with Participant C5 stating, *"Ongoing training and professional development are critical to keep up with advancements in BIM."* The findings underscore the essential importance of education at multiple levels in cultivating a workforce capable of effectively using BIM technologies.

Financial barriers significantly hinder the adoption of BIM, particularly for smaller enterprises. Therefore, the institution of financial incentives becomes a crucial approach to hasten this transition. Both industry experts and government officials have emphasised the importance of introducing subsidies, tax breaks, and various incentives to alleviate the financial burden. Participant IE9 suggested, *"Providing financial incentives like tax breaks would make it easier for smaller firms to adopt BIM."* In the meantime, G4 highlighted that *"increased training opportunities would make BIM adoption more feasible for smaller firms"* dealing with financial limitations. Financial incentives could encourage firms of all sizes to adopt BIM technology and training. This approach fosters a more equitable environment and promotes broader participation in the BIM ecosystem.

Several participants emphasized the critical need for well-defined national standards and guidelines in implementing BIM, identifying this as a notable gap. E10 remarked, *"The lack of national standards for BIM makes it challenging for firms to implement BIM consistently,"* whereas E8 highlighted, *"Developing local BIM standards would be important to ensure consistency across the industry."*

Clients highlighted the importance of having regulatory frameworks that offer clear guidelines. C4 suggested, *"The government should focus on creating a regulatory framework for BIM use with clear guidelines and standards."* Creating these standards would enhance uniformity in BIM practices, enabling more efficient collaboration among different projects and stakeholders. Clients significantly influence the adoption of BIM by mandating its inclusion in project contracts and tender documents. C1 observed, *"...clients can drive BIM adoption by requiring its use in project contracts and tender documents."* By leveraging their influence, clients can create demand for BIM among project teams, which in turn facilitates its integration across the supply chain. Additionally, clients emphasized the importance of stakeholder collaboration in enhancing knowledge sharing and promoting collective growth. Collaborative initiatives, such as co-funded training programs and joint ventures, promise to accelerate the industry's transition to BIM.

The findings suggest that the effective implementation of BIM in Ghana's construction industry requires a coordinated, multi-dimensional strategy that addresses financial, technical, organizational, and regulatory challenges. Respondents consistently emphasized four major pillars of effective BIM implementation: government leadership, education and training, financial incentives, and the establishment of national standards. Together, these strategies form a coherent framework for fostering widespread adoption and ensuring that BIM becomes an integral part of construction practice in Ghana.

Government leadership emerged as the most critical strategy for mainstreaming BIM. Participants stressed that without clear directives, policy frameworks, or mandates, adoption will continue to be slow and inconsistent. Respondents highlighted the role of government in setting benchmarks for the industry by mandating BIM use in public sector projects, particularly large-scale infrastructure works. These mandates would compel firms to adopt BIM as a standard practice, while also creating ripple effects for the private sector. By establishing BIM as a requirement in government-led initiatives, the public sector could set a precedent that encourages wider integration across the industry. This approach would also promote consistency in application, ensuring that BIM is not limited to isolated projects but becomes a foundational practice in Ghana’s construction ecosystem.

Education and training were also identified as pivotal to building the capacity needed for BIM implementation. Respondents strongly advocated for the integration of BIM into academic curricula at universities and technical institutions to prepare future professionals. By embedding BIM into higher education, the next generation of architects, engineers, and project managers can acquire the knowledge and skills necessary to work effectively with the technology. Beyond formal education, participants also emphasized the importance of continuous professional development through workshops, seminars, and specialized training programs. Tailored training sessions for policymakers and industry leaders were seen as equally essential in cultivating a shared understanding of BIM’s benefits. This dual focus—on both preparing new entrants and upskilling current professionals—ensures that the workforce evolves in tandem with technological advancements. In this way, education and training provide the foundation for sustainable BIM adoption.

The financial barriers associated with BIM adoption also necessitate targeted interventions in the form of incentives and subsidies. Many respondents stressed that smaller firms in particular face prohibitive costs when it comes to purchasing licenses, upgrading hardware, or funding staff training. To address these challenges, participants recommended financial support measures such as tax breaks, subsidies, and grants. These interventions would not only ease the burden on resource-constrained firms but also level the playing field, enabling a wider range of stakeholders to participate in the transition to BIM. By reducing the cost of entry, financial incentives could stimulate adoption across the industry and encourage firms to invest in the skills and infrastructure necessary to fully utilize BIM technologies.

Equally important is the establishment of national BIM standards and regulatory frameworks to guide consistent implementation. Respondents underscored the difficulties created by the absence of unified standards, which results in fragmented practices and software incompatibilities across firms and projects. Participants noted that well-defined local standards would foster uniformity, improve collaboration, and reduce inefficiencies in project delivery. Regulatory frameworks developed and enforced by government bodies would provide clear guidelines for stakeholders while reducing uncertainty around contractual and technical responsibilities. Clients also have a significant role to play by requiring BIM adoption in tender documents and project contracts. This contractual requirement would compel firms to adopt BIM, while also reinforcing the need for consistency and quality in its application.

Collaboration among stakeholders was highlighted as a final component that underpins all other strategies. Respondents emphasized that collective efforts, such as co-funded training programs, industry-wide workshops, and joint ventures, could accelerate BIM adoption by promoting shared learning and reducing duplication of effort. Clients, industry leaders, academic institutions, and policymakers must work together to develop initiatives that foster knowledge exchange and support industry-wide innovation. This spirit of collaboration ensures that BIM adoption is not only driven by top-down directives but also supported by bottom-up initiatives within the industry.

4.3 Quantitative Data Analysis

This section presents the results and analysis of the questionnaire survey conducted as part of the study. The analysis is presented in three stages: descriptive analysis, inferential analysis through both exploratory and confirmatory analysis (EFA and CFA), and structural equation modelling (SEM). The Statistical Package for the Social Sciences (SPSS) version 25 was used for descriptive data analysis, reliability testing and exploratory factor analysis (EFA). Meanwhile, AMOS was used for the confirmatory factor analysis (CFA) and structural equation modelling (SEM).

4.3.1 Demographic Information of the Respondents

Descriptive statistics provide a summary of the demographic profile of the respondents, including their gender, age, academic qualification, role, years of experience, and location in Ghana. These initial statistics also capture the organisational type and size. Table 4. 2 below presents a summary of the demographic features of the respondents.

Table 4. 2 Demographic Information of the Respondents

Demographic Information		Freq.	%
Gender	Male	329	86.6
	Female	51	13.4
Age	18-25 years	35	9.2
	26-35 years	148	38.9
	36-45 years	133	35.0
	46-55 years	50	13.2
	Over 55 years	14	3.7
Academic Qualification	Certificate	10	2.6
	HND/Diploma	48	12.6
	Bachelor's Degree	200	52.6
	Master's Degree	109	28.7
	PhD	13	3.4
Role	Architect	142	37.4
	Structural/Civil Engineer	106	27.9
	Mech. Elect. and Plumb. (MEP) Engineers	63	16.6
	Quantity Surveyor	23	6.1
	Construction/Project Manager	43	11.3
	Other	3	0.8
Years Of Experience	1-5 years	212	55.8
	6-10 years	129	33.9
	11-15 years	39	10.3
Organization Type	Consulting	212	55.8
	Construction	129	33.9
	Development Authority	39	10.3
Size Of Organisation	Micro:1-5 employees	29	7.6
	Small: 6-30 employees	64	16.8
	Medium:31-100 employees	156	41.1
	Large: more than 100 employees	131	34.5
Location of Organization	Ashanti Region	69	18.2
	Brong Ahafo Region	15	3.9

Demographic Information		Freq.	%
	Central Region	56	14.7
	Eastern Region	42	11.1
	Greater Accra Region	115	30.3
	Northern Region	6	1.6
	Upper East Region	8	2.1
	Upper West Region	7	1.8
	Volta Region	7	1.8
	Western Region	33	8.7
	Savannah Region	5	1.3
	Bono East Region	6	1.6
	Oti Region	4	1.1
	Ahafo Region	3	0.8
	Western North Region	2	0.5
	North East Region	2	0.5
Total		380	100.0

The sample was predominantly male, comprising 329 respondents (86.6%) compared to only 51 female respondents (13.4%). This indicates a notable gender disparity, which may be reflective of industry-specific trends. Most respondents fell within the age range of 26 to 35 (38.9%), closely followed by those aged 36 to 45 (35.0%). A smaller proportion of respondents fell into the age groups of 18 to 25 years (9.2%), 46 to 55 years (13.2%), and over 55 years (3.7%). This distribution indicates a concentration of respondents in their mid-career stages.

More than half of the respondents (52.6%) held a bachelor's degree, followed by those with a Master's degree (28.7%). Respondents with HND/Diploma qualifications accounted for 12.6% of the sample, while smaller groups had PhD (3.4%) and Certificate qualifications (2.6%). The educational qualification reflects a highly educated respondent pool. Regarding professional roles, Architects formed the largest group (37.4%), followed by Structural/Civil Engineers (27.9%). Other significant roles included MEP Engineers (16.6%), Construction/Project Managers (11.3%), and Quantity Surveyors (6.1%). A minimal fraction (0.8%) was identified with other roles. The distribution reflects the key professional disciplines traditionally involved in the construction industry.

Most respondents (55.8%) had between 1 and 5 years of industry experience, followed by those with 6-10 years (33.9%). Respondents with 11-15 years of

experience constituted 10.3%, indicating a relatively younger workforce. In terms of organizational affiliation, a significant proportion of respondents (55.8%) worked in consulting firms, followed by construction firms (33.9%) and development authorities (10.3%). This highlights the dominance of consulting professionals in the sample, potentially due to their greater exposure to BIM.
Medium-sized organizations with 31-100 employees were most represented (41.1%), followed closely by large organizations (34.5%). Smaller organizations categorised as small (16.8%) and micro (7.6%) accounted for a smaller portion. Geographically, the Greater Accra region recorded the highest representation (30.3%), reflecting its status as Ghana's primary economic and administrative hub. Other well-represented regions included Ashanti (18.2%), Central (14.7%) and Eastern (11.1%). On the contrary, regions such as Northern (1.6%), Bono East (1.6%), Savannah (1.3%), and North-East (0.5%) had minimal representation, highlighting a geographic concentration of professionals in more urbanized and economically active regions.

4.3.2 BIM Adoption

The analysis presented in Table 4. 3 The statement "Our organization is at BIM Level 1 (combining 2D and 3D CAD models)" recorded the highest mean score of 4.97 (SD = 1.804), indicating that most respondents perceive their organizations to be operating at an intermediate level of BIM maturity. Closely following this is the statement "BIM technologies are a fundamental tool guiding our project management and decision-making", which had a mean of 4.72 (SD = 1.765). This suggests a strong recognition of BIM's strategic role in guiding project decisions, although it may not be fully embedded in all operational processes.

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Table 4. 3 BIM Adoption

Items	Mean	Std. Dev.
Our organization is at BIM Level 1 (combining 2D and 3D CAD models).	4.97	1.804
BIM technologies are a fundamental tool guiding our project management and decision-making.	4.72	1.765
Our organization has seamlessly integrated BIM technologies into our routine project practices.	4.28	1.85
Our organization is at BIM Level 0 (2D CAD drawings and paper-based communication).	4.24	1.87
Our organization is at BIM Level 2 (collaborative federated BIM models).	3.39	2.033
Our organization is at BIM Level 3 (full integration with a single shared model among project participants).	2.67	2.011

4.3.2.1 Assessment of the unidimensionality and reliability of the BIM Adoption (BA) construct

The EFA was conducted to assess the unidimensionality and reliability of the BIM Adoption (BA) construct, as shown in Table A 1 (see Appendix A). Principal component analysis with Varimax rotation (PCA Varimax) was employed as the extraction and rotation method. The construct consisted of six measurement items. The Kaiser-Meyer-Olkin (KMO) measure yielded a value of 0.842, which surpasses the recommended threshold of 0.70, while Bartlett's test of sphericity produced a statistically significant result ($p<0.000$), meeting the criteria established by Hair Jr et al. (2021). These outcomes confirm the suitability of the data for factor analysis.

All six items (BA1, BA2, BA3, …, BA6) intended to measure BIM Adoption (BA) loaded onto one component. Factor loadings for all items exceeded the 0.5 threshold, greater than the recommended value of 0.40 suggested by Field (2005) and Hair Jr et al. (2021). The specific loadings unto this component included: "BIM technologies are a fundamental tool guiding our project management and decision-making", "Our organization has seamlessly integrated BIM technologies into our routine project practices.", "Our organization is at BIM Level 1 (combining 2D and 3D CAD models)", "Our organization is at BIM Level 0 (2D CAD drawings and paper-based communication)", "Our organization is at BIM Level 2 (collaborative federated BIM models)," and "Our organization is at BIM Level 3 (full integration with a single shared model among project participants)." Collectively, these items strongly measure BIM Adoption (BA).

Furthermore, corrected item-total correlations were assessed using a recommended cut-off value of 0.30. The analysis confirmed that all items demonstrated strong relationships within the component, with a Cronbach's alpha of 0.80 or higher. This result indicates that the BIM Adoption (BA) construct exhibits acceptable internal reliability, as suggested by Cristobal et al. (2007).

4.3.2.2 SEM for the BIM Adoption Construct

Following the confirmation of the unidimensionality and reliability of the construct through EFA, a CFA was conducted. The analysis of goodness of fit for the BIM Adoption (BA) Construct followed a three-statistic strategy of fit indices as recommended by Hu and Bentler (1999). The sample data on the model yielded an S–Bχ2 value of 2.603 with 5 degrees of freedom (df) and a significance probability of $p = 0.0000$. Although this chi-square value indicates a significant departure of the sample data from the postulated model, it still suggests a good fit. The chi-square test is very sensitive to sample size and is used more as a descriptive index of fit rather than as a statistical test (Kline, 2010).

Furthermore, analysis of the fit indices revealed a CFI value of 0.904, higher than the recommended threshold of 0.90, indicating that the model is considered acceptable. The NFI value was 0.903, within the given range, given the minimum cut-off of 0.90, as shown in Table 4. 4. The PNFI recorded a value of 0.446, which is below the cut-off value of 0.80. Also, the RMR of 0.023 is less than 0.05, and the GFI value of 0.922 is greater than 0.90. These fit indices suggest that the hypothesised BIM Adoption (BA) model adequately describes the sample data. Therefore, it can be included in the full latent variable model analysis (Table 4. 4).

Table 4. 4 Robust Fit Index for the BIM Adoption Indicators

Fit Index	Cut-Off Value	Estimate	Comment
$S-B\chi^2$		2.603	
Df	0≥	5	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.904	Acceptable
PCFI	Less than 0.80	0.281	Good fit
RMSEA	Less than 0.08	0.048	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.012	Acceptable
NFI	Greater than 0.90 “good fit”	0.903	Good fit
IFI	Greater than 0.90 “good fit”	0.900	Good fit
PNFI	Less than 0.80	0.446	Good fit
RMR	Less than 0.05 “good fit”	0.023	Acceptable
GFI	Greater than 0.90 “good fit”	0.922	Good fit

Figure 4. 1 illustrate the unidimensional model for the BIM Adoption (BA) Construct. Out of the six (6) indicator variables, five (BA1, BA2, BA3, BA4 and BA5) were obtained and used for the final CFA analysis (Byrne, 2013). These five indicator variables were analysed using data from 380 cases.

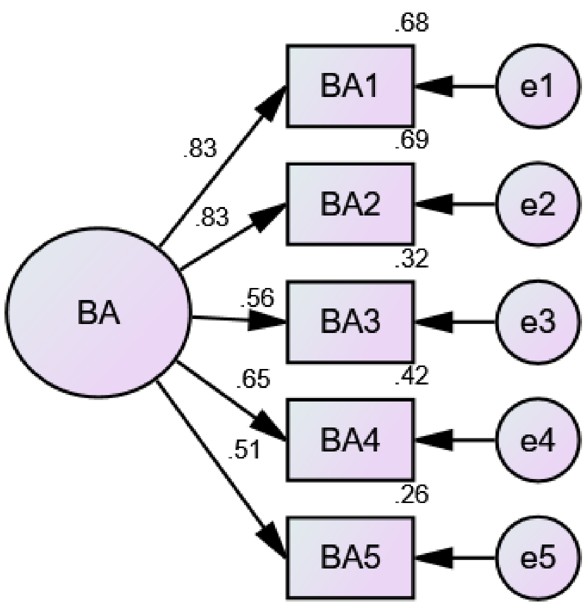

Figure 4. 1 CFA Model for BIM Adoption Indicators

All correlation values were less than the maximum threshold of 1.00, with each indicator exhibiting a statistically significant relationship ($p<0.05$) in the expected direction (see Appendix A, Table A 3). Thus, these parameter estimates are both reasonable and statistically significant. The indicator variable BA2 displayed the highest standardized coefficient (0.830), suggesting its particularly strong association with the underlying BIM adoption construct.

4.3.3 BIM Awareness and Knowledge

4.3.3.1 BIM Awareness

The analysis presented Table 4. 5 reveals a generally high level of awareness among respondents regarding various dimensions of BIM. Most of the statements recorded mean scores above 5.0, corresponding to levels between "Agree Somewhat" and "Strongly Agree" on the Likert scale. The highest-ranked item, "I understand that BIM helps improve the overall visualization of a construction project," attained the highest mean score of 5.97 (SD = 1.178), an RII of 0.852, and was ranked 1st, indicating widespread and strong agreement among respondents about BIM's role in enhancing project visualization.

Following closely, statements such as "I am aware that BIM represents the future of managing project information in construction" (mean = 5.92, SD = 1.319, RII = 0.845, rank = 2) and "I am aware of the concept of BIM" (mean = 5.90, SD = 1.419, RII = 0.842, rank = 3) reflect sound general awareness about the strategic importance and conceptual underpinnings of BIM. Moreover, the statement "I am aware that BIM is more than 3D modelling; it involves managing project information" ranked 4th (mean = 5.88, SD = 1.225, RII = 0.840), reinforcing the understanding that BIM extends beyond graphical representation to encompass integrated management of project data.

Substantial awareness was also evident in perceptions of BIM's impact on quality, communication, coordination, clash detection, and rework reduction, with all related statements ranking within the top ten and registering RII values ranging from 0.832 to 0.824. This indicates a strong consensus regarding the benefits of BIM to construction efficiency and coordination.

Moderate awareness levels were observed for more technical or specialized aspects of BIM. For instance, "I am aware of BIM maturity levels and their implications for project collaboration" (mean = 5.47, SD = 1.373, RII = 0.781, rank = 16) and "I know that BIM can be used for facility management after project completion" (mean = 5.26, SD = 1.445, RII = 0.751, rank = 17) reflect some recognition, but lower relative emphasis compared to broader conceptual or benefit-related items.

The lowest levels of awareness were associated with more niche-specific areas. "I am familiar with international BIM standards" and "I am aware of BIM roadmaps for implementation in the construction industry" recorded lower mean scores of 4.85 and 4.91, respectively, with RII values of 0.692 (rank = 19) and 0.701 (rank = 18). The statement "I am aware that BIM can be applied during the design phase for 3D visualizations and simulations" was the lowest ranked (mean = 4.51, SD = 1.377, RII = 0.644), suggesting a relatively weaker understanding of specific BIM applications in the design stage.

Standard deviation values, which ranged from 1.178 to 1.591, highlight variability in awareness levels across different BIM components. Notably, the highest variability (SD = 1.591) was observed in the statement about BIM's use during construction to monitor progress and detect clashes, indicating differing degrees of experience or familiarity among respondents. In contrast, lower standard deviations for high-ranked items such as project visualization and quality improvement suggest a stronger consensus.

Table 4. 5 BIM Awareness

Items	Mean	Std. Dev.	RII	Rank
I understand that BIM helps improve the overall visualization of a construction project.	5.97	1.178	0.852	**1**
I am aware that BIM represents the future of managing project information in construction.	5.92	1.319	0.845	**2**
I am aware of the concept of BIM.	5.9	1.419	0.842	**3**
I am aware that BIM is more than 3D modelling; it involves managing project information.	5.88	1.225	0.84	**4**
I am aware that BIM improves the quality of construction outcomes.	5.87	1.168	0.838	**5**

Items	Mean	Std. Dev.	RII	Rank
I hear more about BIM in industry discussions now than in the past.	5.83	1.323	0.832	**6**
I am aware that BIM helps in the detection of clashes in designs.	5.8	1.246	0.828	**7**
I am aware that BIM reduces errors and the need for rework in construction projects.	5.78	1.183	0.825	**8**
I am aware that BIM enhances communication and coordination between project stakeholders.	5.77	1.18	0.824	**9**
I am aware that BIM allows faster and more efficient decision-making in project execution.	5.75	1.243	0.821	**10**
I am aware of how BIM significantly changes the traditional workflow in the construction industry.	5.73	1.18	0.818	**11**
I understand BIM is all about real time collaboration throughout a project's lifecycle.	5.65	1.346	0.807	**12**
I am aware of the difference between BIM and traditional 3D CAD systems.	5.64	1.434	0.805	**13**
I am aware that BIM helps in reducing project costs.	5.63	1.324	0.804	**14**
I believe that following BIM roadmaps is important for successful implementation.	5.57	1.274	0.795	**15**
I am aware of BIM maturity levels and their implications for project collaboration.	5.47	1.373	0.781	**16**
I know that BIM can be used for facility management after project completion	5.26	1.445	0.751	**17**
I am aware of BIM roadmaps for implementation in the construction industry	4.91	1.581	0.701	**18**
I am familiar with international BIM standards.	4.85	1.545	0.692	**19**
I am aware that BIM is used during the construction phase to monitor progress and detect clashes.	4.76	1.591	0.68	**20**
I am aware that BIM can be applied during the design phase for 3D visualizations and simulations.	4.51	1.377	0.644	**21**

4.3.3.1.1 Assessment of the unidimensionality and reliability of the BIM Awareness construct

EFA was conducted to assess the unidimensionality and reliability of the BIM Awareness construct. PCA Varimax was specified as the extraction and rotation method. A total of twenty-one items were used to measure the Construct. The analysis yielded a KMO value of 0.951 and Bartlett’s test of sphericity with a significance level of $p < 0.000$. These results meet the recommended thresholds, precisely a KMO value above 0.70 and Bartlett’s test of sphericity of $p<0.05$ (Hair Jr et al., 2021). These results confirmed that factor analysis could be conducted with the data.

All items intended to measure the BIM Awareness construct loaded onto four distinct components (see appendix A, Table A 4). Using a factor loading threshold of 0.5, which exceeds the recommended value of 0.40 (Field, 2005; Hair Jr et al., 2021), all items exceeded this threshold for the respective components.

The first component included eight (8) items measuring awareness of BIM concepts (C). These items include the following statements: “I am aware that BIM represents the future of managing project information in construction”, “I am aware of how BIM significantly changes the traditional workflow in the construction industry”, “I am aware that BIM is more than 3D modelling; it involves managing project information.”, “I am aware that BIM is all about real-time collaboration throughout a project's lifecycle.”, “I hear more about BIM in industry discussions now than in the past.”, “I am aware of BIM maturity levels and their implications for project collaboration”, “I am aware of the concept of BIM”, and “I am aware of the difference between BIM and traditional 3D CAD systems”. Collectively, these items represented the concept-related dimension of BIM awareness.

The second component consisted of seven (7) items focusing on BIM benefits (B). They included, “I am aware that BIM improves the quality of construction outcomes.” “I am aware that BIM helps improve the overall visualization of a construction project”, “I am aware that BIM enhances communication and coordination between project stakeholders”, “I am aware that BIM reduces errors and the need for rework in construction projects”, “I am aware that BIM helps detect clashes in designs.”, “I am aware that BIM allows faster and more efficient decision-making in project execution", and "I am aware that BIM helps in reducing project costs".

The third component comprised three (3) items related to BIM standards and roadmaps (SR). They included "I am aware of BIM roadmaps for implementation in the construction industry", "I am familiar with international BIM standards", and "I believe that following BIM roadmaps is important for successful implementation." This dimension reflected awareness of BIM standards and roadmaps.

The fourth component included three (3) items concerning awareness of the use of BIM during various project phases (PP). These items included: "I am aware that BIM is used during the construction phase to monitor progress and detect clashes.", "I am aware that BIM can be applied during the design phase for 3D visualizations and simulations", and "I know that BIM can be used for facility management after project completion."

After identifying the components through EFA, corrected item-total correlations were examined, applying a threshold of 0.30. All items were confirmed as strong indicators, demonstrating strong internal consistency, with Cronbach's alpha values exceeding 0.800 for each identified component, indicating acceptable internal reliability.

4.3.3.1.2 Structural Equation Model (SEM) for the BIM Awareness Construct

A CFA was conducted after establishing sufficient unidimensionality and reliability using EFA. The evaluation of model fit for the BIM Awareness Construct employed a three-statistics strategy to assess goodness-of-fit. The CFA results indicated an acceptable model fit. The model yielded the S–Bχ2 of 2.505 with 183 degrees of freedom (df) at a significance level of $p = 0.0000$. Although this chi-square statistic indicates a departure of the sample data from the model, it is very sensitive to sample size and typically serves as a descriptive index of fit rather than a statistical test (Kline, 2023).

The CFI value was 0.908, more significant than the recommended cut-off limit of 0.90, indicating an acceptable model fit. The NFI value was 0.912, also meeting the recommended criterion of $\geq .90$, as shown in Table 4. 6. Additionally, the PNFI value obtained was 0.772, although slightly below the ideal cut-off of

0.80, and remains acceptable in conjunction with the other fit indicators. The RMR was 0.038, less than 0.05, and GFI was 0.924, greater than the standard threshold of 0.90. These fit indices collectively suggest that the postulated BIM Awareness Construct model adequately describes the sample data and can be included in the full latent variable model analysis.

Table 4. 6 Robust Fit Index for BIM Awareness

Fit Index	Cut-Off Value	Estimate	Comment
$S - B\chi^2$		2.505	
Df	0≥	183	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.908	Acceptable
PCFI	Less than 0.80	0.772	Good fit
RMSEA	Less than 0.08	0.034	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.018	Acceptable
NFI	Greater than 0.90 “good fit”	0.912	Good fit
IFI	Greater than 0.90 “good fit”	0.909	Good fit
PNFI	Less than 0.80	0.756	Good fit
RMR	Less than 0.05 “good fit”	0.038	Acceptable
GFI	Greater than 0.90 “good fit”	0.924	Good fit

Figure 4. 2 present the unidimensional model for the BIM Awareness Construct. All twenty-one (21) indicator variables were obtained and utilized for the final CFA analysis. The analysis based on 380 cases, resulted in these indicator variables being categorised into four (4) distinct components: Concept (C), consisting of items C1, C2, C3, C4, C5, C6, C7 and C8; Benefits (B), consisting of items B1, B2, B3, B4, B5, B6 and B7; Standards and Roadmaps (SR), consisting of items SR1, SR2, and SR3; and Project Phase (PP), PP1, PP2 and PP3.

All the correlation coefficients were less than 1.00 and exhibited p-values less than the significance threshold of 0.05, with appropriate directional signs. Thus, the estimates were deemed reasonable and statistically significant. Among the parameters, the indicator variable SR1 had the highest standardized coefficient at 0.928 (see Appendix A, Table A 6).

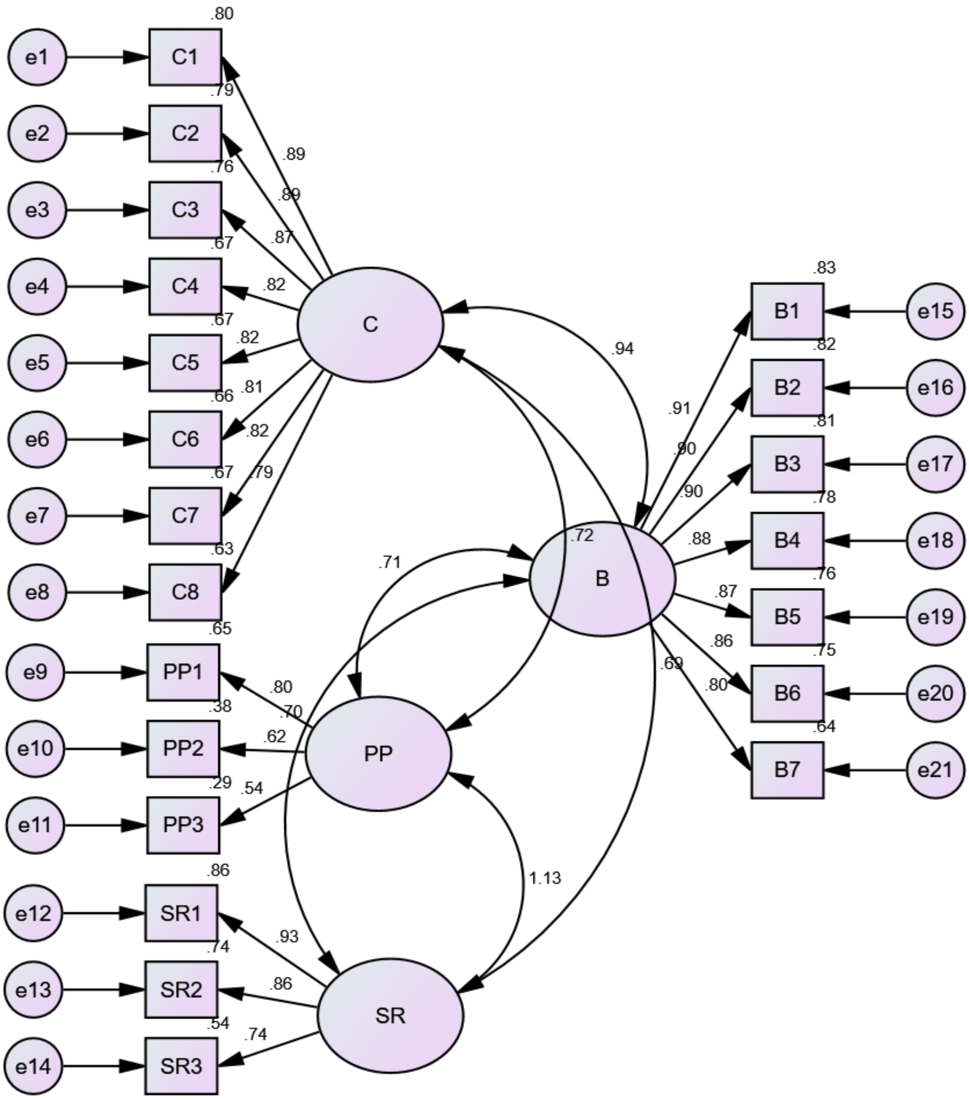

Figure 4. 2 CFA Model for BIM Awareness

4.3.3.1.3 Assessing the Impact of BIM Awareness on BIM Adoption

SEM in AMOS was used to assess the influence of BIM awareness, comprising four dimensions: concepts (C), benefits (B), standards and roadmaps (SR), and project phase (PP) on BIM adoption (BA). The primary objective was to evaluate the extent to which these dimensions of BIM awareness contribute to BIM adoption. Establishing an adequate model fit is a critical step in SEM analysis, as it verifies that the hypothesized relationships align with the observed data, thereby enhancing the reliability of the findings. The analysis yielded an S-Bχ^2 value of 10.705 with 295 degrees of freedom (df) and a p-value of 0.000. While a significant chi-square value indicates some discrepancy between the sample data and the proposed model, in SEM, this does not inherently indicate poor model fit. Instead, it suggests that the model captures substantial relationships among the examined constructs. The results confirm that the proposed model adequately explains how BIM awareness, as measured through its four identified dimensions, influences BIM adoption.

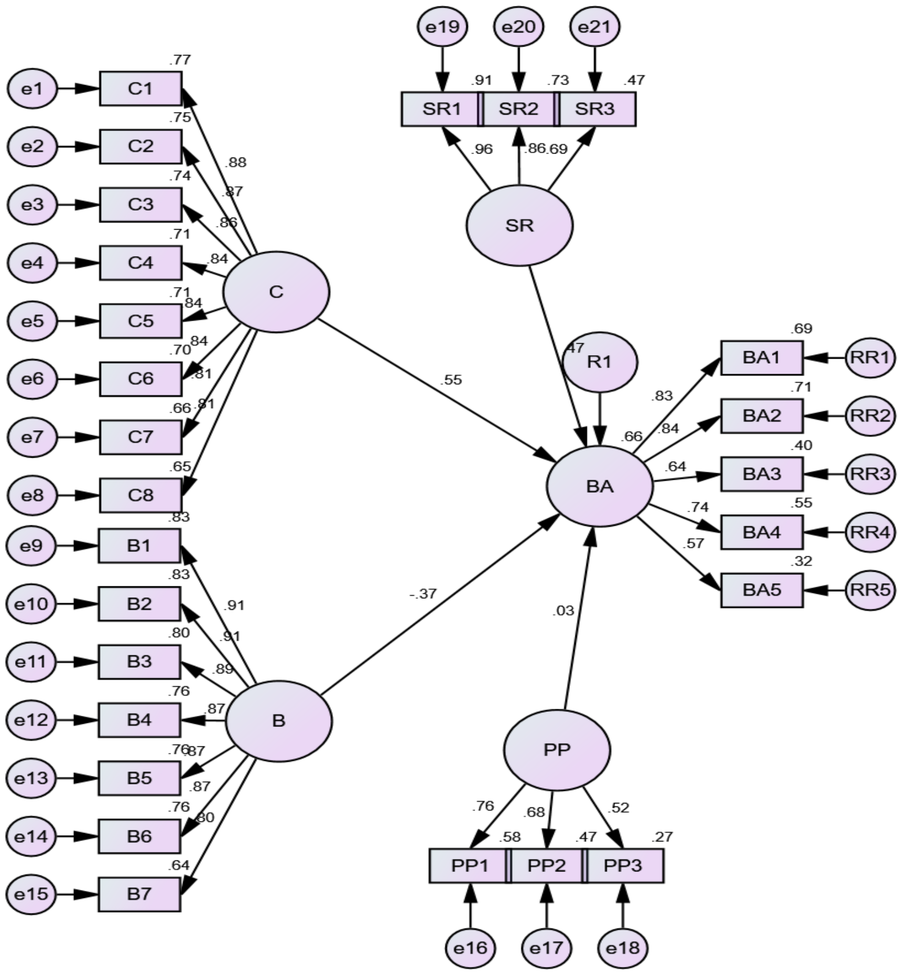

Figure 4. 3 SEM For the Effect of BIM Awareness *(Concepts (C), Benefits (B), Standards and Roadmaps (SR), Project Phase (PP))* on BIM Adoption (BA)

Table 4. 7 presents the correlation values, standard errors and the test statistics. All correlation values were less than 1.00, with the p-values being smaller than the 0.05 significance level. The parameter with the highest standardized coefficient was the C on BA, with a parameter coefficient of 0.471.

Table 4. 7 Factor Loading and P-Value of The Effect of the Influence of BIM Awareness on BIM Adoption (BA)

Hypothesized relationships (Path)			Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
BA	←	SR	0.898	0.471	0.000	0.664	Yes
BA	←	C	0.800	0.552	0.000		Yes
BA	←	B	-0.580	-0.369	0.000		Yes
BA	←	PP	0.039	0.028	0.807		No

Concept =C, Benefits=B, Standards and roadmaps=SR, Project Phase=PP and BIM Adoption =BA

The findings indicate that SR has a positive and significant effect on BIM adoption, with a standardized coefficient of 0.471 (p = 0.000). These results suggest that familiarity with BIM standards and roadmaps strongly contributes to BIM adoption, as professionals and organizations guided by clear frameworks and protocols are more likely to integrate BIM into their operations. Similarly, C exhibits a stronger positive and significant influence on BIM adoption, with a standardized coefficient of 0.552 (p = 0.000). This finding underscores the importance of conceptual understanding in promoting BIM adoption, suggesting that greater awareness and understanding of BIM principles significantly enhance its adoption.

In contrast, B demonstrates a negative yet significant relationship with BIM adoption, reflected by a standardized coefficient of -0.369 (p = 0.000). This inverse relationship may imply that while the theoretical benefits of BIM are acknowledged, practical challenges - such as cost, lack of case studies, or resistance to change - might hinder its adoption. On the other hand, the PP variable shows no significant impact on BIM adoption, with a standardized coefficient of 0.028 and a p-value of 0.807 (above the 5% significance threshold). This suggests that BIM is perceived by professionals as beneficial or challenging, irrespective of the specific project phase in which it is introduced. Thus, awareness of its use at a specific phase of the project lifecycle becomes less critical in the overall adoption process.

The R-square value of 0.664 indicates that approximately 66.4% of the variance in BIM adoption can be explained by the combined influence of BIM awareness constructs (C, B, SR, and PP). This substantial explanatory power demonstrates the importance of awareness-related factors as key drivers of BIM adoption. However, the negative relationship, coupled with perceived benefits and the insignificance of the project phase, highlights the need for further exploration into additional factors that influence BIM adoption in practice.

4.3.3.2 BIM Knowledge

Table 4. 8 highlights the respondents' knowledge and proficiency across various aspects of BIM. The mean scores predominantly range between 4.0 and 5.0 on a 7-point Likert scale, suggesting that respondents possess moderate familiarity and competence with BIM-related tasks and concepts. The highest-rated item, "I am proficient in using BIM software," recorded a mean score of 4.92 (SD = 1.838), an RII of 0.703, and ranked 1st, indicating a relatively high level of self-assessed operational proficiency among respondents. Similarly, "I can manipulate 3D models using BIM software" followed closely with a mean of 4.90 (SD = 1.817), a RII of 0.700, and a rank of 2.

Respondents also demonstrated moderate proficiency in tasks such as generating automatic schedules and quantities (mean = 4.70, SD = 1.910, RII = 0.671, rank = 3) and understanding the procedural steps for BIM implementation (mean = 4.68, SD = 1.815, RII = 0.669, rank = 4). These results suggest a foundational understanding of BIM operational tools and project integration steps.

Slightly lower mean scores were recorded for more advanced BIM competencies, such as "I am familiar with developing and following a BIM Execution Plan (BEP)" (mean = 4.46, SD = 1.855, RII = 0.637, rank = 8) and "I can run clash detection using BIM software" (mean = 4.32, SD = 1.755, RII = 0.617, rank = 10), reflecting areas where respondents expressed less confidence or had limited exposure. Similarly, while "I have gained practical experience by working on BIM projects" scored moderately (mean = 4.52, SD = 1.877, RII = 0.646, rank = 7), the findings suggest a need for more hands-on experience across the industry.

Respondents reported even lower proficiency in more specialized areas. For instance, "I understand how 4D BIM (scheduling) and 5D BIM (estimating) are applied in construction projects" had the lowest mean score of 4.12 (SD = 2.047), an RII of 0.589, and was ranked 14th. This suggests that advanced BIM applications remain underutilized or poorly understood. Similarly, "I am familiar with the integration of BIM with emerging technologies such as virtual reality (VR) and augmented reality (AR)" (mean = 4.29, RII = 0.613, rank = 11) reflects limited awareness of cross-disciplinary innovations involving BIM.

Notably, items related to training and organizational support showed mixed responses. "I have received formal training in BIM software and processes" had a mean of 4.27 (SD = 1.839, RII = 0.610, rank = 12), and "My organization provides opportunities for continuous BIM training and development" had a mean of 4.13 (SD = 1.991, RII = 0.590, rank = 13). These scores suggest that while some respondents have accessed training, a significant number lack consistent support or access to structured BIM development opportunities.

The standard deviation values ranged from 1.755 to 2.047, indicating substantial variability in responses. The highest variability was observed in responses regarding understanding of 4D/5D BIM applications, underscoring the divergent levels of experience and exposure. Similar disparities were noted in perceptions of organizational support for BIM training, indicating inconsistencies in institutional efforts across the sector.

Table 4. 8 BIM Knowledge

Items	Mean	Std. Dev.	RII	Rank
I am proficient in using BIM software.	4.92	1.838	0.703	**1**
I can manipulate 3D models using BIM software	4.9	1.817	0.700	**2**
I can generate automatic schedules and quantities using BIM tools.	4.7	1.91	0.671	**3**
I understand the steps required to implement BIM on a project.	4.68	1.815	0.669	**4**

Items	Mean	Std. Dev.	RII	Rank
I know how to export/import BIM data using various file formats.	4.66	1.807	0.666	**5**
I know how to work collaboratively with other disciplines using a BIM model.	4.58	1.888	0.654	**6**
I have gained practical experience by working on BIM projects.	4.52	1.877	0.646	**7**
I am familiar with developing and following a BIM Execution Plan (BEP).	4.46	1.855	0.637	**8**
I know the concept of Digital Twins and its relationship with BIM for real-time data management and simulation.	4.35	1.915	0.621	**9**
I can run clash detection using BIM software.	4.32	1.755	0.617	**10**
I am familiar with the integration of BIM with emerging technologies, such as virtual reality (VR) and augmented reality (AR).	4.29	1.939	0.613	**11**
I have received formal training in BIM software and processes.	4.27	1.839	0.610	**12**
My organization provides opportunities for continuous BIM training and development.	4.13	1.991	0.590	**13**
I understand how 4D BIM (scheduling) and 5D BIM (estimating) are applied in construction projects.	4.12	2.047	0.589	**14**

4.3.3.2.1 Assessment of the unidimensionality and reliability of the BIM knowledge construct

EFA was conducted to assess the unidimensionality and reliability of the BIM knowledge construct. PCA Varimax was used as the extraction and rotation method, employing fourteen items to measure the Construct. The KMO value was 0.883, accompanied by a Bartlett's test of sphericity result of $p<0.000$. These values indicate consistency with the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p<0.05$, which confirms that factor analysis could be conducted with the data.

The analysis resulted in all fourteen items loading onto four distinct components (see Table A 7 in appendix A), each with factor loadings exceeding 0.5, which is greater than the recommended value of 0.40 (Field, 2005; Hair Jr et al., 2021).

The first component included five items: “I know how to export/import BIM data using various file formats”, “I can manipulate 3D models using BIM software”, “I can generate automatic schedules and quantities using BIM tools.”, “I am proficient in using BIM software”, and “I can run clash detection using BIM software”. These items collectively measure knowledge in Fundamentals of BIM (F).

The second component consisted of three items exceeding the 0.5 threshold. They are “I understand the steps required to implement BIM on a project.”, “I know how to work collaboratively with other disciplines using a BIM model”, and “I am familiar with developing and following a BIM Execution Plan (BEP)”. This component is labelled BIM Implementation in Projects (IP).

The third component consisted of three (3) items: “I have gained practical experience by working on BIM projects”, “I have received formal training in BIM software and processes”, and “My organization provides opportunities for continuous BIM training and development.” These items measure Training and Knowledge Acquisition in BIM (TK).

The fourth component consisted of three items with loadings above 0.5. They included: “I am familiar with the integration of BIM with emerging technologies, such as virtual reality (VR) and augmented reality (AR)”, “I know the concept of Digital Twins and its relationship with BIM for real-time data management and simulation” and “I understand how 4D BIM (scheduling) and 5D BIM (estimating) are applied in construction projects”. These items measure Advanced BIM Knowledge (ABK).

Following component extraction through EFA, the corrected item-total correlations were evaluated using the recommended threshold of 0.30. All items demonstrated compelling measurement capacity for their respective components, as confirmed by Cronbach’s alpha values exceeding 0.800. These results indicate acceptable internal reliability (Cristobal et al., 2007).

4.3.3.2.2 Structural Equation Model (SEM) for BIM Knowledge Construct

After the constructs demonstrated sufficient evidence of unidimensionality and reliability through EFA, a CFA was then administered. The analysis strategy for goodness of fit for the BIM Knowledge Construct followed a three-statistic strategy of fit indices (Hu & Bentler, 1999). The sample data on the model yielded the S–Bχ2 of 3.751 with 71 degrees of freedom (df) and a probability of p = 0.0000. The chi-square value indicated that the departure of the sample data from the postulated model was significant, indicating a good fit.

The CFI value was calculated to be 0.942, greater than the cut-off limit of 0.90, suggesting an acceptable model fit. The NFI value of 0.934 also exceeded the recommended cut-off value of NFI ≥ 0.90, further supporting model acceptability as shown in Table 4. 9. The PNFI value obtained was 0.446, which is below the cut-off value of 0.80. Also, the RMR was 0.019, which is below 0.05, and the GFI value was 0.925, exceeding 0.90. These fit indices for the BIM Knowledge Construct model suggested that the postulated model adequately describes the sample data and could be included in the full latent variable model analysis (Table 4. 9).

Table 4. 9 Robust Fit Index for BIM Knowledge

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
S – Bχ^2		3.751	
Df	0≥	71	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.942	Acceptable
PCFI	Less than 0.80	0.735	Good fit
RMSEA	Less than 0.08	0.034	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.022	Acceptable
NFI	Greater than 0.90 “good fit”	0.934	Good fit
IFI	Greater than 0.90 “good fit”	0.942	Good fit
PNFI	Less than 0.80	0.729	Good fit
RMR	Less than 0.05 “good fit”	0.019	Acceptable

Fit Index	Cut-Off Value	Estimate	Comment
GFI	Greater than 0.90 "good fit"	0.925	Good fit

Figure 4. 4 present the unidimensional model for the BIM Knowledge Construct features. The final CFA analysis retained and utilised all fourteen indicator variables initially considered. From the 380 cases analysed, these fourteen indicator variables were categorised as follows: F (F1, F2, F3, F4, and F5), IP (IP1, IP2, and IP3), TK (TK1, TK2, and TK3), and ABK (ABK1, ABK2, and ABK3).

All correlation values were less than 1.00, and the corresponding p-values were below the significant threshold value of 0.05, indicating statistical significance and appropriate directional relationships (see Appendix A Table A 9). The indicator with the highest standardized coefficient was the indicator with variable IP1; its parameter coefficient was 0.966.

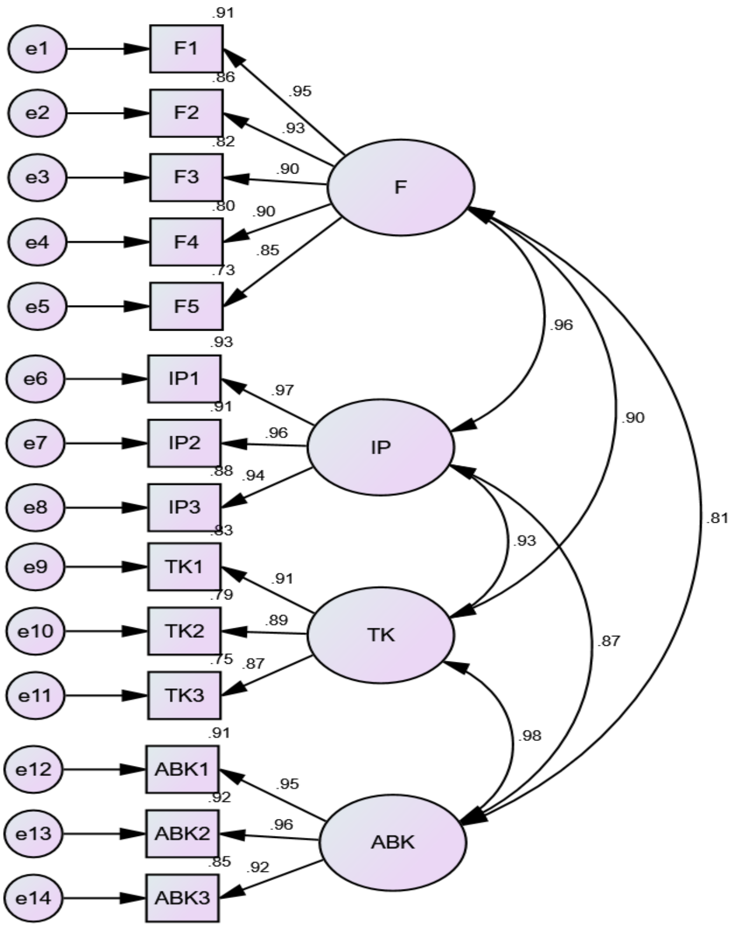

Figure 4. 4 CFA Model for the BIM Knowledge Indicators

4.3.3.2.3 Testing The Influence of BIM Knowledge on BIM Adoption

SEM in AMOS was conducted to assess the impact of BIM knowledge comprising Fundamentals of BIM (F), BIM Implementation in Projects (IP), Training and Knowledge Acquisition (TK), and Advanced BIM Knowledge (ABK) on BIM Adoption (BA). Before analysis, model fit indices were evaluated to ensure they met the recommended thresholds, as suggested by Hu and Bentler (1999). The analysis yielded an S-B χ^2 value of 20.382 with 148 degrees of freedom (df) and a p-value of 0.000. While this significant chi-square value indicates a deviation between the sample data and the hypothesized model, in SEM, it does not necessarily imply a poor fit; instead, it signifies that the model effectively captures the relationships between BIM knowledge and BIM adoption. The results confirm that the proposed model provides a strong statistical fit, adequately representing the data and supporting the hypothesized influence of BIM knowledge on BIM adoption. Figure 4. 5 below illustrates the SEM framework, depicting the structural relationships between BIM knowledge components and BIM adoption.

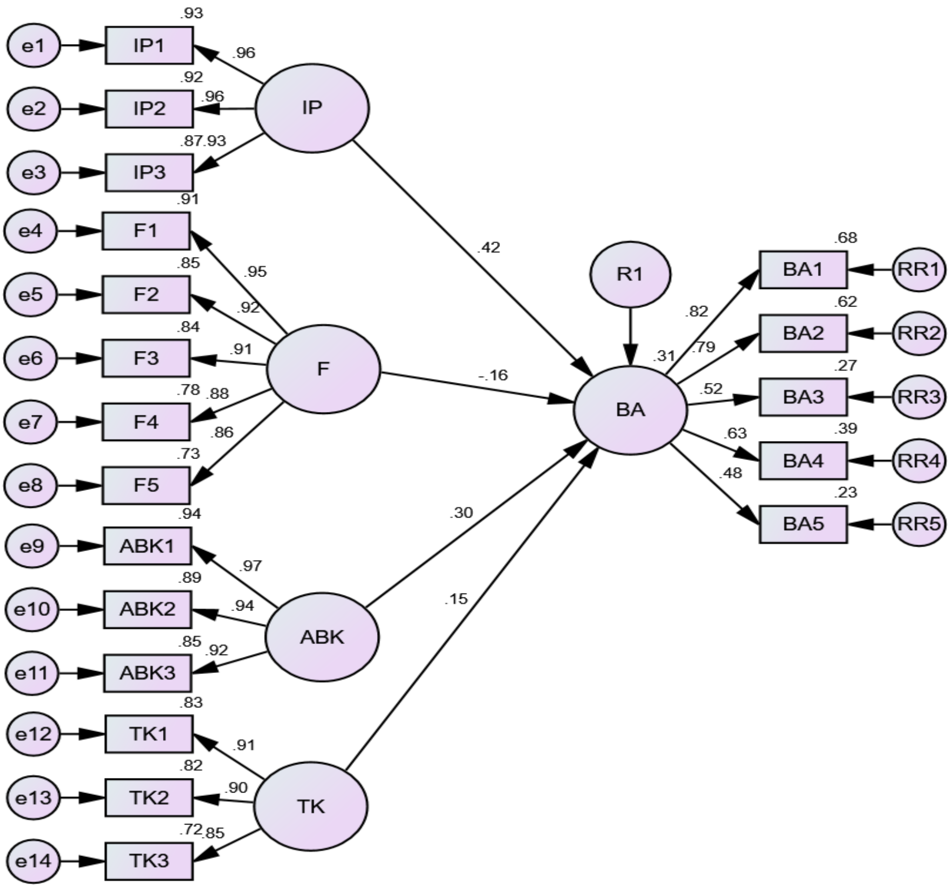

Figure 4. 5 SEM for the effect of BIM Knowledge *(Fundamentals of BIM (F), BIM Implementation in Projects (IP), Training and Knowledge Acquisition in BIM (TK) and Advanced BIM Knowledge (ABK))* on BIM Adoption (BA)

Table 4. 10 presents the correlation values, standard errors, and statistical test results. All correlation values were below 1.00, confirming the absence of multicollinearity. Additionally, all p-values were below 0.05, demonstrating statistical significance at the 5% level.

Table 4. 10 Factor loading and P-value of the effect of BIM Knowledge on BIM Adoption (BA)

Hypothesized relationships (Path)			Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
BA	←	IP	0.349	0.423	0.000	0.495	Yes
BA	←	F	-0.131	-0.156	0.268		No
BA	←	ABK	0.228	0.297	0.000		Yes
BA	←	TK	0.130	0.154	0.355		No

Fundamentals of BIM =F, BIM Implementation in Projects =IP, Training and Knowledge Acquisition in BIM =TK and Advanced BIM Knowledge=ABK

The results are evaluated based on factor loadings, p-values, and R-square values to determine the significance and strength of these relationships.

The findings indicate that IP has the strongest positive influence on BIM Adoption, with a standardized coefficient (λ) of 0.423 and a p-value of 0.000, confirming statistical significance at the 5% level. The R-square value of 0.495 suggests that nearly 50% of the variance in BIM Adoption can be explained by BIM knowledge, mainly through practice.

ABK also shows a statistically significant positive relationship with BIM Adoption, with a standardized coefficient of 0.297 and a p-value of 0.000. This result suggests that professionals with advanced knowledge of BIM are more likely to implement the technology, emphasizing the importance of continuous learning and skill development in BIM-related processes.

Conversely, F and TK do not exhibit significant effects on BIM Adoption, with standardized coefficients of -0.156 and 0.154, respectively, and p-values above the 0.05 threshold. The negative coefficient for F suggests that merely having foundational BIM knowledge does not necessarily translate into higher adoption rates. Similarly, the non-significant effect of TK implies that training alone may not be sufficient to drive BIM adoption unless it is paired with organizational drive.

4.3.3.3 Differences in BIM Awareness and Knowledge Among Construction Professionals

Understanding variations in BIM awareness and knowledge across different professional groups is crucial for identifying expertise gaps and guiding targeted training initiatives. A one-way ANOVA was conducted to assess whether significant differences exist in BIM awareness and knowledge levels among architects, structural/civil engineers, MEP engineers, quantity surveyors, construction/project managers, and other professionals. The results of this analysis, presented in Table 4. 11 and Table 4. 12, provide insights into which professional groups have higher or lower familiarity with BIM concepts, helping to inform future capacity-building efforts in Ghana’s construction industry.

Table 4. 11 One-Way ANOVA Results for Differences in BIM Awareness and Knowledge Among Construction Professionals

Profession	N	Mean	Std Dev.
Architect	142	4.25	0.55
Structural/Civil Engineer	106	3.88	0.60
MEP Engineers	63	3.75	0.63
Quantity Surveyor	23	3.50	0.67
Construction/Project Manager	43	3.95	0.59
Other	3	3.30	0.70
Total	380	3.78	0.64

A one-way ANOVA test was conducted to determine whether there is a significant difference in BIM awareness and knowledge levels among various construction professionals. The results indicate a statistically significant difference across professional groups ($F = 9.34$, $p = 0.0001$). Since the p-value is less than 0.05, we reject the null hypothesis and accept the alternative hypothesis, confirming that BIM awareness and knowledge significantly vary among construction professionals in Ghana’s construction industry.

Among the professional groups, architects reported the highest mean BIM awareness and knowledge score (M = 4.25, SD = 0.55), indicating a strong familiarity with BIM concepts and applications. Structural/Civil Engineers (M = 3.88, SD = 0.60) and Construction/Project Managers (M = 3.95, SD = 0.59) also reported relatively high levels of BIM awareness. On the other hand, Quantity Surveyors (M = 3.50, SD = 0.67) and the other category (M = 3.30, SD = 0.70) reported the lowest levels of BIM awareness and knowledge, suggesting that professionals in these roles may require additional training and exposure to BIM practices.

Table 4. 12 *ANOVA Results*

Statistic	Value
F-Statistic	9.34
p-Value	0.0001
Significance	Significant at $p < 0.05$

The high F-statistic (9.34) indicates that the differences among groups are statistically significant and not due to random variation. The significant variation in BIM awareness across professional groups highlights the need for targeted BIM education and training programs tailored to specific professions, particularly Quantity Surveyors and other professionals who showed lower awareness and knowledge levels.

4.3.4 Organizational and Technological readiness of Ghana’s construction industry towards BIM adoption

The analysis presented Table 4. 13 provides detailed insights into the organizational and technological readiness for BIM adoption among the surveyed organizations. Responses were measured using a Likert scale, where higher mean scores signify stronger agreement. The highest-rated item was “BIM training in our organization is mostly self-led by employees”, which had a mean score of 4.97 (SD

= 1.638), RII of 0.710, and ranked 1st. This suggests a significant reliance on individual initiative rather than structured organizational training programs.

Statements reflecting strategic alignment also ranked highly. “The implementation of BIM aligns with our organization's long-term goals” and “Our management believes that BIM will lead to long-term benefits despite the initial challenges of implementation”, recorded mean scores of 4.86 and 4.85, respectively, with RII values of 0.694 and 0.693, ranking 2nd and 3rd. These indicate a strong strategic belief in the long-term value of BIM, even though operational readiness may still be developing.

BIM integration into project workflows varied, with “BIM technologies are integrated into only the design stage” ranked 4th (mean = 4.81, RII = 0.687), suggesting partial integration is more common than full project lifecycle adoption. The statement “BIM technologies are integrated into every stage of our project workflow, from design to construction and beyond” was the lowest-ranked item (rank = 28, mean = 4.15, RII = 0.593), underscoring that full lifecycle integration remains limited.

Collaboration capabilities were also evaluated. Respondents expressed strong agreement that their “workforce is capable of collaborating effectively across disciplines in BIM projects” (mean = 4.77, RII = 0.681, rank = 5), supported by moderately high agreement with “cross-disciplinary collaboration being encouraged” (mean = 4.57, RII = 0.653, rank = 15). Skills related to using BIM for coordination and communication were acknowledged with moderate confidence (mean = 4.61, RII = 0.659, rank = 11; and mean = 4.56, RII = 0.651, rank = 16, respectively).

In terms of workforce readiness, organizations generally reported adequate staff competence. “Our organization has enough staff with the required skills to implement BIM” (mean = 4.65, RII = 0.664, rank = 9) and “Employees are encouraged to pursue BIM certifications” (mean = 4.60, RII = 0.657, rank = 13) suggest reasonable, though not outstanding, support for professional development. Nevertheless, structured training programs lagged. “Regular in-house training sessions” and “Access to external BIM training programs” were ranked 20th and

24th respectively (RII = 0.636 and 0.633), indicating a need for more institutionalized capacity-building efforts.

Organizational strategies and systems also reflected readiness gaps. “A clearly defined and documented strategy for the implementation of BIM” received a relatively low ranking (rank = 27, mean = 4.30, RII = 0.614), pointing to a lack of formal strategic planning in many organizations. Similarly, “There is a systematic approach in place for monitoring and evaluating the progress of BIM implementation” was ranked 17th (RII = 0.640), revealing another area for improvement in governance and oversight.

Technological readiness was assessed through investment in tools and infrastructure. “Our organization has invested in the latest BIM software” had a modest mean of 4.41 (RII = 0.630, rank = 25), while “We regularly invest in upgrading technological infrastructure” ranked even lower (rank = 26, RII = 0.621). This suggests that although some investments are being made, they are not yet at a level that would fully support seamless BIM integration.

Despite these limitations, there were strengths in IT support systems. “Our organization has a dedicated IT or technical support team” and “Reliable IT infrastructure for BIM use” received mean scores of 4.70 and 4.61, respectively, with both ranking within the top 15 (RII = 0.671 and 0.659, ranks = 6 and 11), demonstrating that some foundational systems are in place.

Table 4. 13 Organisational and Technological Readiness

Items	Mean	Std. Dev.	RII	Rank
BIM training in our organization is mostly self-led by employees.	4.97	1.638	0.710	**1**
The implementation of BIM aligns with our organization's long-term goals.	4.86	1.584	0.694	**2**
Our management believes that BIM will lead to long-term benefits despite the initial challenges of implementation.	4.85	1.61	0.693	**3**
BIM technologies are integrated into only the design stage of our project workflows.	4.81	1.647	0.687	**4**

Items	Mean	Std. Dev.	RII	Rank
Our workforce is capable of collaborating effectively across disciplines (e.g., architects, engineers, contractors) in BIM projects.	4.77	1.679	0.681	**5**
Our organization has a dedicated IT or technical support team.	4.7	1.817	0.671	**6**
Our management fosters a culture of innovation that supports the adoption of BIM across all levels of the organization.	4.7	1.616	0.671	**6**
The effectiveness of our BIM training programs is measured through feedback and improved application of learned skills.	4.68	1.662	0.669	**8**
Our organization has enough staff with the required skills to implement BIM.	4.65	1.695	0.664	**9**
Our project management processes are adapted to accommodate BIM.	4.62	1.629	0.660	**10**
Our organization has a reliable IT infrastructure capable of handling the demands of BIM software efficiently.	4.61	1.845	0.659	**11**
Our workforce understands how to use BIM for better coordination between different project teams.	4.61	1.729	0.659	**11**
Employees are encouraged and supported to pursue professional BIM certification programs.	4.6	1.716	0.657	**13**
Senior management in our organization is committed to adopting new technologies like BIM.	4.6	1.706	0.657	**13**
Our organization encourages cross-disciplinary collaboration among different departments for BIM implementation.	4.57	1.793	0.653	**15**
Our workforce is skilled at using BIM to facilitate communication and data sharing between various stakeholders in a project.	4.56	1.722	0.651	**16**

Items	Mean	Std. Dev.	RII	Rank
There is a systematic approach in place for monitoring and evaluating the progress of BIM implementation within our organization.	4.48	1.641	0.640	**17**
The use of BIM tools is an integral part of our project planning.	4.47	1.71	0.639	**18**
Our organization employs professionals with specialized skills and expertise in utilizing BIM.	4.46	1.741	0.637	**19**
We have established systems for secure and efficient data sharing and collaboration.	4.45	1.873	0.636	**20**
Our organization offers employees regular in-house training sessions on BIM.	4.45	1.911	0.636	**20**
BIM technologies are integrated into both the design and construction stages of our project workflow.	4.45	1.702	0.636	**20**
A significant portion of our workforce has received formal BIM training or certifications.	4.44	1.778	0.634	**23**
Our organization provides access to external BIM training programs to enhance the BIM-related skills of our workforce.	4.43	1.81	0.633	**24**
Our organization has invested in the latest BIM software to support project workflows.	4.41	1.844	0.630	**25**
We regularly invest in upgrading our technological infrastructure to support the seamless integration of BIM-related technologies.	4.35	1.878	0.621	**26**
Our organization has a clearly defined and documented strategy for the implementation of BIM.	4.3	1.645	0.614	**27**
BIM technologies are integrated into every stage of our project workflow, from design to construction and beyond.	4.15	1.78	0.593	**28**

4.3.4.1 Assessment of the unidimensionality and reliability of the Organisational and Technological Readiness construct

EFA was conducted to assess the unidimensionality and reliability of the Organisational and Technological Readiness construct. PCA Varimax was employed as the extraction and rotation method. A total of twenty-eight items measured the Construct. The Kaiser-Meyer-Olkin (KMO) measure was 0.964, and Bartlett's test of sphericity was significant ($p<0.000$), indicating consistency with the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p<0.05$ suggested by Hair et al. (2010). These results suggested that factor analysis could be conducted with the data.

Applying a factor loading threshold of 0.5 for factor loading, which is greater than the recommended value of 0.40 by Field (2005) and Hair Jr et al. (2021), all 28 items were significantly loaded onto three (3) distinct components (see Appendix A, Table A 11).

The first component comprised thirteen (13) items: "Our organization employs professionals with specialized skills and expertise in utilizing BIM", "Our workforce is skilled at using BIM to facilitate communication and data sharing between various stakeholders in a project", "A significant portion of our workforce has received formal BIM training or certifications", "Our organization has enough staff with the required skills to implement BIM", "Our project management processes are adapted to accommodate BIM", "BIM technologies are integrated into both the design and construction stages of our project workflow", "BIM technologies are integrated into every stage of our project workflow, from design to construction and beyond", "The use of BIM tools is an integral part of our project planning", "Our organization encourages cross-disciplinary collaboration among different departments for BIM implementation", "Our workforce understands how to use BIM for better coordination between different project teams", "Our organization offers employees regular in-house training sessions on BIM", "Our organization provides access to external BIM training programs to enhance the BIM-related skills of our workforce", "There is a systematic approach in place for monitoring and evaluating the progress of BIM implementation within our organization" and "Our workforce is capable of collaborating effectively across disciplines (e.g., architects, engineers, contractors) in BIM projects". These items measure BIM Capability and Integration (BCI).

The second component also includes eight (8) items: "We have established systems for secure and efficient data sharing and collaboration", "Our organization has a reliable IT infrastructure capable of handling the demands of BIM software efficiently", "We regularly invest in upgrading our technological infrastructure to support the seamless integration of BIM related technologies", "Our organization has a dedicated IT or technical support team", "Our organization has invested in the latest BIM software to support project workflows", "BIM training in our organization is mostly self-led by employees", "Employees are encouraged and supported to pursue professional BIM certification programs" and "The effectiveness of our BIM training programs is measured through feedback and improved application of learned skills". These items measure the BIM Infrastructure and Skills Development (BISD).

The third component contained five (5) items: "Our management believes that BIM will lead to long-term benefits despite the initial challenges of implementation", "Our management fosters a culture of innovation that supports the adoption of BIM across all levels of the organization", "Senior management in our organization is committed to adopting new technologies like BIM", "The implementation of BIM aligns with our organization's long-term goals", and "Our organization has a clearly defined and documented strategy for the implementation of BIM". These items measure BIM Leadership and Strategic Alignment (BLSA).

Following component extraction, corrected item-total correlations were assessed with a threshold of 0.30. Cronbach's alpha values for all components exceeded 0.800, indicating strong internal reliability (Amron et al., 2020).

4.3.4.2 SEM for the Organisational and Technological Readiness Construct

A CFA was then conducted following the confirmation of unidimensionality and reliability through EFA. The goodness-of-fit evaluation for the Organisational and Technological Readiness Indicators followed a three-statistics strategy of fit indexes as recommended by Hu and Bentler (1999). As presented in Table 4. 14, the Organisational and Technological Readiness model yielded an S–Bχ2 value of 8.835 with 296 degrees of freedom (df) and a p-value of 0.0000. Although this chi-square value indicates a deviation of the sample data from the proposed model, it is generally recognised that chi-square tests are very sensitive to sample size and thus often used descriptively rather than conclusively (Kline, 2005).

The CFI value of 0.946 exceeded the acceptable cut-off limit of 0.90, indicating a good model fit. Similarly, the NFI value was 0.930, which falls within the recommended criterion (NFI ≥ .90) for acceptability. The PNFI was 0.756, slightly below the ideal cut-off value of 0.80. Also, the RMR of 0.029 is less than 0.05, and the GFI value of 0.965 exceeds the threshold of 0.90. These fit indices suggest that the hypothesised Organisational and Technological Readiness model adequately describes the sample data and is suitable for inclusion in the full latent variable model analysis.

Table 4. 14 Robust Fit Index for the Organisational and Technological Readiness

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
$S - B\chi^2$		8.835	
Df	0≥	229	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.946	Acceptable
PCFI	Less than 0.80	0.771	Good fit
RMSEA	Less than 0.08	0.051	Good fit
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.027	Good fit
NFI	Greater than 0.90 “good fit”	0.930	Good fit
IFI	Greater than 0.90 “good fit”	0.947	Good fit
PNFI	Less than 0.80	0.756	Good fit
RMR	Less than 0.05 “good fit”	0.029	Good fit
GFI	Greater than 0.90 “good fit”	0.965	Good fit

The unidimensional model for Organisational and Technological Readiness Indicators is presented in Figure 4. 6. All twenty-eight (28) indicator variables identified from the EFA were used for the final CFA analysis (Jöreskog, 1988; Byrne, 2013). From the 380 cases analysed for this construct, the final set of indicators consisted of seven components realised as BCI (BCI1, BCI2, BCI3,

BCI4, BCI5, BCI6, BCI7, BCI8, BCI 9, BCI10, BCI11, BCI12 and BCI13), BISD (BISD1, BISD2, BISD3, BISD4, BISD5, BISD6, BISD7, and BISD8) and BLSA (BLSA1, BLSA2, BLSA3, BLSA4, and BLSA5).

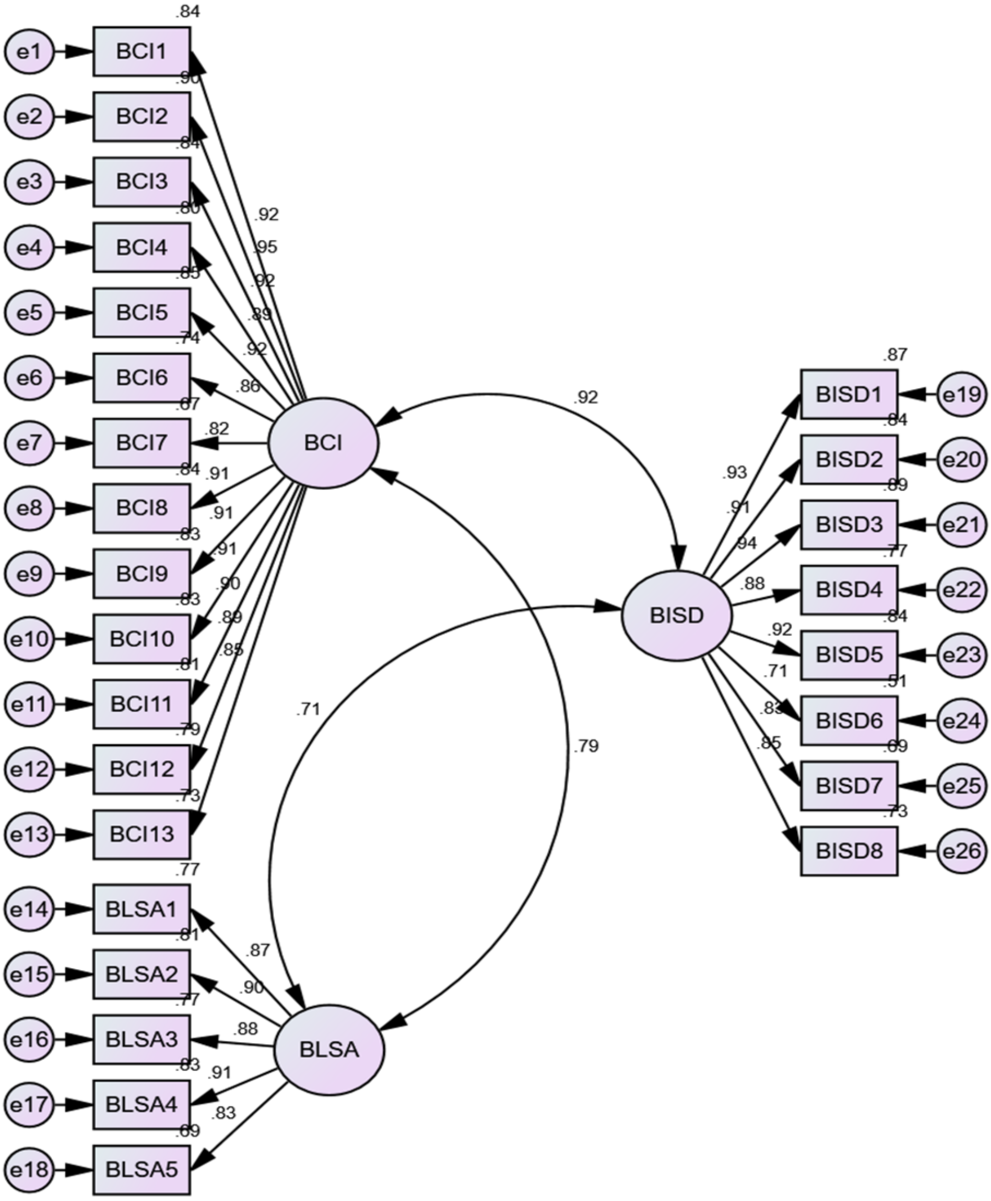

Figure 4. 6 CFA Model for the Organisational and Technological Readiness

All correlation coefficients were below the threshold of 1.00, with corresponding p-values less than the significant value of 0.05 and showed appropriate signs (see Appendix Table A 12). The estimates were, therefore, deemed reasonable and statistically significant. Among the parameters, the indicator BCI2 exhibited the highest standardised coefficient value of 0.950.

4.3.4.3 Testing The Influence of Organisational and Technological Readiness on BIM Adoption (BA)

SEM using AMOS was conducted to evaluate the impact of Organizational and Technological Readiness on BIM Adoption (BA). The key organisational and technological readiness factors analysed included BIM Capability and Integration (BCI), BIM Infrastructure and Skills Development (BISD) and BIM Leadership and Strategic Alignment (BLSA). Before analysis, model fit indices were assessed to ensure they met the recommended thresholds, following the guidelines of Hu and Bentler (1999).

The analysis yielded a Satorra–Bentler Chi-square (S-Bχ^2) value of 9.624 with 431 degrees of freedom (df) and a p-value of 0.000. Although this chi-square value indicates some deviation between the sample data and the hypothesized model, in SEM, this does not necessarily imply poor model fit. Instead, it suggests that the model effectively captures the relationships between organizational and technological readiness factors and BIM adoption.

The results demonstrate that the proposed model exhibits a strong statistical fit, accurately representing the data and affirming the hypothesized influence of organizational and technological readiness on BIM adoption. In particular, factors such as management attitude, BIM implementation strategies, and technological infrastructure emerged as critical factors significantly influencing BIM adoption. Figure 4. 7 illustrates the SEM framework, clearly depicting the structural relationships between organizational and technological readiness factors and BIM adoption.

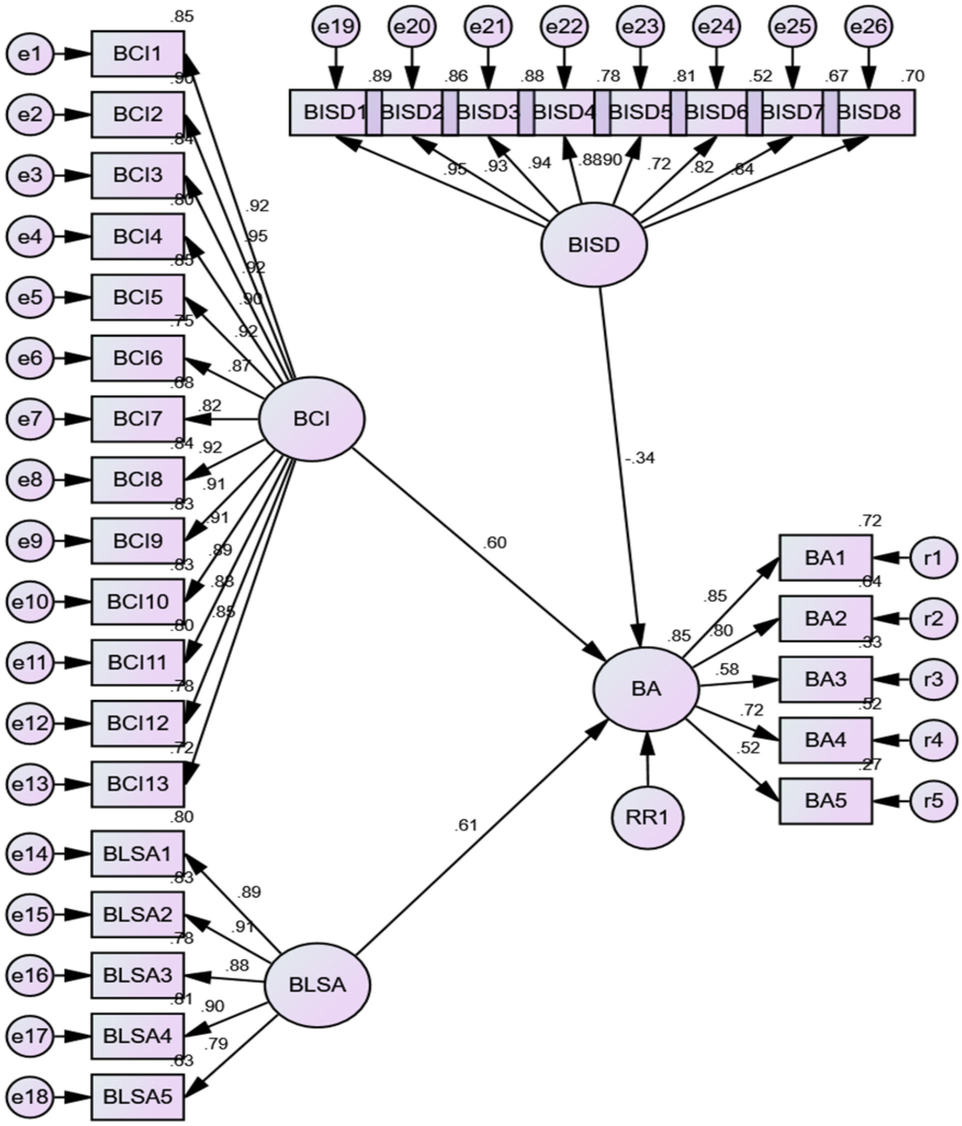

Figure 4. 7 SEM for the effect of Organisational and Technological *Readiness (BIM Capability and Integration (BCI), BIM Infrastructure and Skills Development (BISD) and BIM Leadership and Strategic Alignment (BLSA)* on BIM Adoption (BA)

Table 4. 15 presents the correlation values, standard errors, and statistical test results. All correlation values reported in the table are below 1.00, confirming the absence of multicollinearity among variables. Additionally, all p-values are less than 0.05 significance level, indicating statistical significance at the 5% threshold. Among the analysed parameters, BIM Leadership and Strategic Alignment (BLSA) exhibited the highest standardized coefficient 0.607), demonstrating a strong positive relationship between BLSA and BIM Adoption (BA).

Table 4. 15 Factor loading and P-value of the effect of Organisational and Technological Readiness on the BIM Adoption (BA)

Hypothesized relationships (Path)			Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
BA	←	BISD	-0.315	-0.343	0.000	0.846	Yes
BA	←	BCI	0.608	0.600	0.000		Yes
BA	←	BLSA	0.686	0.607	0.000		Yes

BIM Capability and Integration (BCI), BIM Infrastructure and Skills Development (BISD) and BIM Leadership and Strategic Alignment (BLSA)

The obtained R-square value of 0.846 indicates that the three Organizational and Technological Readiness factors collectively account for 85.2% of the variance in BIM adoption, suggesting a strong predictive capacity in explaining BIM adoption within the industry.

All three hypothesized relationships demonstrate statistical significance at the 5% level ($p < 0.001$), confirming the validity of each pathway in the model. However, the nature and magnitude of these relationships vary considerably.

BLSA emerges as the most influential predictor of BIM adoption, with the highest standardized coefficient ($\beta = 0.607$, $p < 0.001$). This strong positive relationship indicates that organizations with committed leadership, well-defined strategic vision, and clear managerial support for digital transformation are more likely to successfully adopt BIM technologies. The finding underscores the critical role of top-down organizational commitment in driving technological innovation.

BCI demonstrates a robust positive influence on BIM adoption ($\beta = 0.600$, $p < 0.001$), nearly matching the effect of leadership factors. This indicates that organizational readiness in terms of internal capabilities, integration processes, and collaborative frameworks is essential for successful BIM implementation. Organizations with well-established integration mechanisms and collaborative cultures create conducive environments for BIM adoption.

Contrary to expectations, BISD shows a significant negative relationship with BIM adoption ($\beta = -0.343$, $p < 0.001$). This counterintuitive finding suggests that current deficiencies in technological infrastructure and workforce skills development actually impede BIM adoption efforts. The negative coefficient indicates that inadequate technical infrastructure, insufficient digital systems, and gaps in employee training create barriers rather than facilitators for BIM implementation.

The analysis reveals a paradoxical situation where “leadership and capability” strongly promote BIM adoption, while “technological infrastructure and skills” currently act as impediments. This suggests that many organizations may have the strategic intent and organizational culture necessary for BIM adoption but lack the fundamental technological foundation and human capital development required for successful implementation.

4.3.5 Key Drivers and Barriers Influencing BIM Adoption

Table 4. 16 sheds light on the key drivers influencing the adoption of BIM within organizations. The responses reveal a wide range of motivational factors, with mean scores spanning from 3.64 to 5.34 on the Likert scale. These results indicate varying degrees of agreement, from moderate to strong, regarding what motivates BIM adoption in Ghana’s construction sector.

The most influential driver was “The overall improvement in construction project quality due to BIM”, which achieved the highest mean score of 5.34 (SD = 1.676), RII of 0.763, and ranked 1st. This demonstrates a strong consensus among respondents that BIM's contribution to improving project quality is a principal reason for its adoption. Closely following were “BIM adoption provides a competitive edge in winning new construction projects” and “BIM’s capability to reduce errors,” both with mean scores of 5.30, RII values of 0.757, and joint ranks of 2. These underscore the recognition of BIM as a tool for enhancing competitive advantage and reducing design and construction errors.

Other significant motivators included “BIM’s capability to improve decision-making” (mean = 5.28, RII = 0.754, rank = 4), “Its ability to streamline workflows and improve collaboration” (mean = 5.25, RII = 0.750, rank = 5), and “Its capacity to reduce project risks by early clash detection” (mean = 5.24, RII = 0.749, rank = 6). These high-ranking drivers highlight that BIM is primarily valued for its operational and project performance benefits, including data management and inter-stakeholder coordination.

Economic drivers were also prominent. "The potential for long-term return on investment (ROI)" and "BIM's ability to improve stakeholder collaboration" both had mean scores of 5.16, RII values of 0.737, and tied at rank 8. Additionally, "Efficiency gains" (mean = 5.09, RII = 0.727, rank = 11) and "BIM's potential to reduce project costs" (mean = 5.07, RII = 0.724, rank = 12) reflect strong perceptions of BIM's financial benefits.

Moderate support was found for enablers such as "The increasing availability of BIM training programs and certifications" (mean = 4.95, RII = 0.707, rank = 13), while external pressures such as "Client demand for BIM-based delivery" (mean = 4.54, RII = 0.649, rank = 14) and "Regulatory policies" (mean = 4.02, RII = 0.574, rank = 15) showed lower levels of influence. These findings suggest that while internal organizational benefits primarily drive BIM uptake, client expectations and regulations are not major compelling motivators.

The least influential driver was "Government incentives have played a significant role in encouraging BIM adoption," which scored the lowest mean (3.64), RII (0.520), and was ranked 16th. This suggests that policy-based financial incentives are perceived as limited or lacking in effect, pointing to an area where increased government intervention could help accelerate adoption.

Standard deviation values ranged from 1.648 to 2.006, reflecting varying degrees of consensus. Notably, the highest variability was observed for perceptions of government incentives (SD = 2.006), indicating divergent views among respondents regarding the effectiveness of these incentives. In contrast, drivers related to quality and efficiency improvements had lower standard deviations, indicating more consistent recognition of these benefits across the sample.

Table 4. 16 Key Drivers Influencing BIM Adoption

Items	Mean	Std. Dev.	RII	Rank
The overall improvement in construction project quality due to BIM is a key driver for adoption.	5.34	1.676	0.763	**1**
BIM adoption provides a competitive edge in winning new construction projects.	5.3	1.728	0.757	**2**

Items	Mean	Std. Dev.	RII	Rank
BIM's capability to reduce errors has motivated our organization to integrate these technologies.	5.3	1.704	0.757	**2**
BIM's capability to improve decision-making has motivated our organization to integrate these technologies.	5.28	1.724	0.754	**4**
BIM's ability to streamline workflows and improve collaboration is a key driver for adoption.	5.25	1.648	0.750	**5**
BIM's ability to reduce project risks by identifying potential issues early in the design phase drives adoption.	5.24	1.722	0.749	**6**
The capability of BIM to manage project data more efficiently is a significant factor in its adoption.	5.22	1.713	0.746	**7**
The potential for long-term return on investment (ROI) from BIM adoption is a key driver.	5.16	1.706	0.737	**8**
BIM's ability to improve collaboration between different project stakeholders drives our organization to adopt it.	5.16	1.717	0.737	**8**
The growing industry trend toward digital transformation has prompted our organization to embrace BIM as a competitive advantage.	5.13	1.827	0.733	**10**
The efficiency gains associated with BIM technologies motivates us to adopt it.	5.09	1.802	0.727	**11**
BIM’s potential to reduce project costs motivates us to adopt it.	5.07	1.817	0.724	**12**
The increasing availability of BIM training programs and certification for our workforce motivates BIM adoption.	4.95	1.785	0.707	**13**
The demand from clients for BIM-based project delivery motivates us to adopt BIM.	4.54	2.011	0.649	**14**
Regulatory policies have played a significant role in encouraging BIM adoption within our organization.	4.02	1.941	0.574	**15**
Government incentives have played a significant role in encouraging BIM adoption within our organization.	3.64	2.006	0.520	**16**

4.3.5.1 Assessment of the unidimensionality and reliability of the Key Drivers Influencing BIM Adoption construct

The EFA was conducted to assess the unidimensionality and reliability of the Key Drivers Influencing BIM Adoption construct (Table A 13, Appendix A). Principal component analysis with Varimax rotation (PCA Varimax) was used as the extraction and rotation method. The analysis involved sixteen items designed to measure the construct. The Kaiser-Meyer-Olkin (KMO) of 0.924 with Bartlett's test of sphericity of $p<0.000$ was obtained, indicating consistency with the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p<0.05$ (Hair et al., 2010). These results confirmed the suitability of the dataset for factor analysis.

Using a factor loading threshold of 0.5, greater than the recommended value of 0.40 by Field (2005) and Hair Jr et al. (2021), all sixteen items exceeded this threshold and loaded onto a single component representing the Key Drivers Influencing BIM Adoption construct.

These items included: "The capability of BIM to manage project data more efficiently is a significant factor in its adoption", "BIM's ability to reduce project risks by identifying potential issues early in the design phase drives adoption", "The growing industry trend toward digital transformation has prompted our organization to embrace", "BIM as a competitive advantage", "BIM's ability to improve collaboration between different project stakeholders drives our organization to adopt it.", "BIM's capability to improve decision-making has motivated our organization to integrate these technologies.", "The overall improvement in construction project quality due to BIM is a key driver for adoption.", "BIM's capability to reduce errors has motivated our organization to integrate these technologies.", "BIM's ability to streamline workflows and improve collaboration is a key driver for adoption", "The increasing availability of BIM training programs and certification for our workforce motivates BIM adoption", "BIM adoption provides a competitive edge in winning new construction projects", "The efficiency gains associated with BIM technologies motivates us to adopt it.", "The potential for long-term return on investment (ROI) from BIM adoption is a key driver", "BIM's potential to reduce project costs motivates us to adopt it", "The demand from clients for BIM-based project delivery motivates us to adopt BIM.", "Government incentives have played a significant role in encouraging BIM adoption within our organization", and "Regulatory policies have played a significant role in encouraging BIM adoption within our organization."

After the component extraction, corrected item-total correlations were evaluated using the recommended threshold of 0.30. All items demonstrated strong internal consistency, as indicated by a Cronbach's alpha value of 0.974, exceeding the threshold of 0.800. Thus, indicating acceptable internal reliability (Amron, Ibrahim, Bakar & Chuprat, 2020).

4.3.5.2 SEM for Key Drivers Influencing BIM Adoption

Following evidence of unidimensionality and reliability established through EFA, a CFA was conducted for the construct (Table 4. 17). The model's goodness of fit was assessed following a three-statistics strategy of fit indices outlined by Hu and Bentler (1999). The CFA yielded an S–Bχ2 of 7.050 with 104 degrees of freedom (df) and a significant p-value ($p = 0.0000$). The chi-square value indicated that the departure of the sample data from the postulated model was significant, indicating a good fit. The chi-square test is very sensitive to sample size and is used more as a descriptive index of fit rather than as a statistical test (Kline, 2005).

The CFI value 0.909 exceeded the acceptable cut-off limit of 0.90, signifying a good model fit. Similarly, the NFI value was 0.900, which falls within the given range (NFI ≥ 0.90), indicating an acceptable model fit. The PNFI value was 0.693, slightly below the threshold of 0.80 yet still within an acceptable range. Also, the RMR of 0.032 is less than 0.05, and the GFI value of 0.932 is greater than 0.90. These fit indices indicate that the postulated model adequately describes the sample data and could be included in the full latent variable model analysis (Table 4. 17).

Table 4. 17 Robust Fit Index for Key Drivers Influencing BIM Adoption

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
$S - B\chi^2$		7.050	
Df	0≥	104	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.909	Acceptable

PCFI	Less than 0.80	0.701	Good fit
RMSEA	Less than 0.08	0.042	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.062	Acceptable
NFI	Greater than 0.90 “good fit”	0.900	Good fit
IFI	Greater than 0.90 “good fit”	0.909	Good fit
PNFI	Less than 0.80	0.693	Good fit
RMR	Less than 0.05 “good fit”	0.032	Acceptable
GFI	Greater than 0.90 “good fit”	0.932	Good fit

The unidimensional model for the Key Drivers Influencing BIM Adoption Construct is presented in Figure 4. 8. All sixteen (16) indicator variables identified were retained and used for the final CFA analysis (Jöreskog,1988; Byrne, 2013). From the 380 analysed cases, these sixteen indicator variables collectively form a single component labelled Key Drivers (KD), comprising KD1 to KD16.

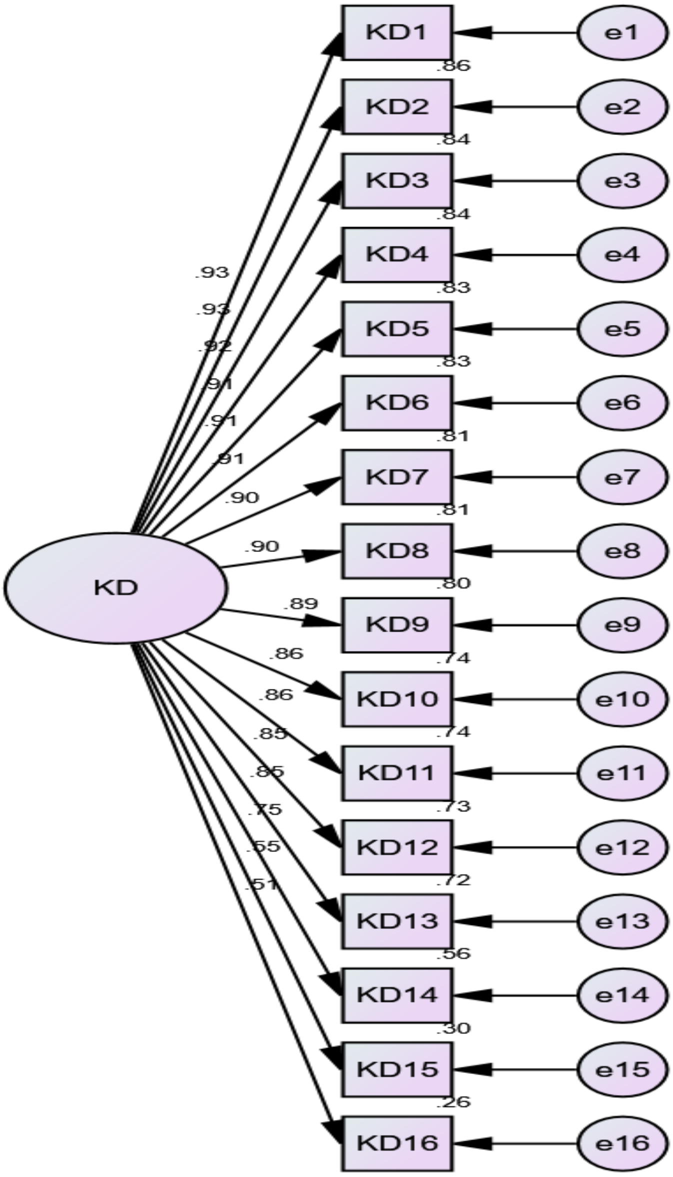

Figure 4. 8 CFA Model for the Key Drivers Influencing BIM Adoption Indicators

Table A presents the correlation values, standard errors and the test statistics for the final 16-indicator model. All correlation values were less than 1.00, and all corresponding p-values were less than the significant value of 0.05, indicating statistical significance and appropriate directional relationships. Therefore, the parameter estimates were considered reasonable and statistically significant. The highest standardized coefficient was observed for the indicator KD1, with a value of 0.929.

4.3.5.3 Testing The Influence of Key Drivers (KD) of BIM Adoption Construct on BIM Adoption (BA)

SEM in AMOS was conducted to assess the impact of Key Drivers (KD) of the BIM Adoption Construct on BIM Adoption (BA). Prior to analysis, model fit indices were evaluated to ensure they met the recommended thresholds, following the guidelines provided by Hu and Bentler (1999). The analysis yielded an S-Bχ^2 value of 11.738 with 188 degrees of freedom (df) and a p-value of 0.000. Although this significant chi-square value suggests some deviation between the sample data and the hypothesized model, in SEM analysis, this does not necessarily indicate a poor model fit. Instead, it suggests that the model adequately captures the structural relationships between the KD and BA.

The results confirm that the proposed model exhibits a strong statistical fit, accurately representing the data and validating the hypothesized impact of KD on BA. Figure 4. 9 illustrates the SEM framework, clearly depicting the structural relationships between the KD construct and BA.

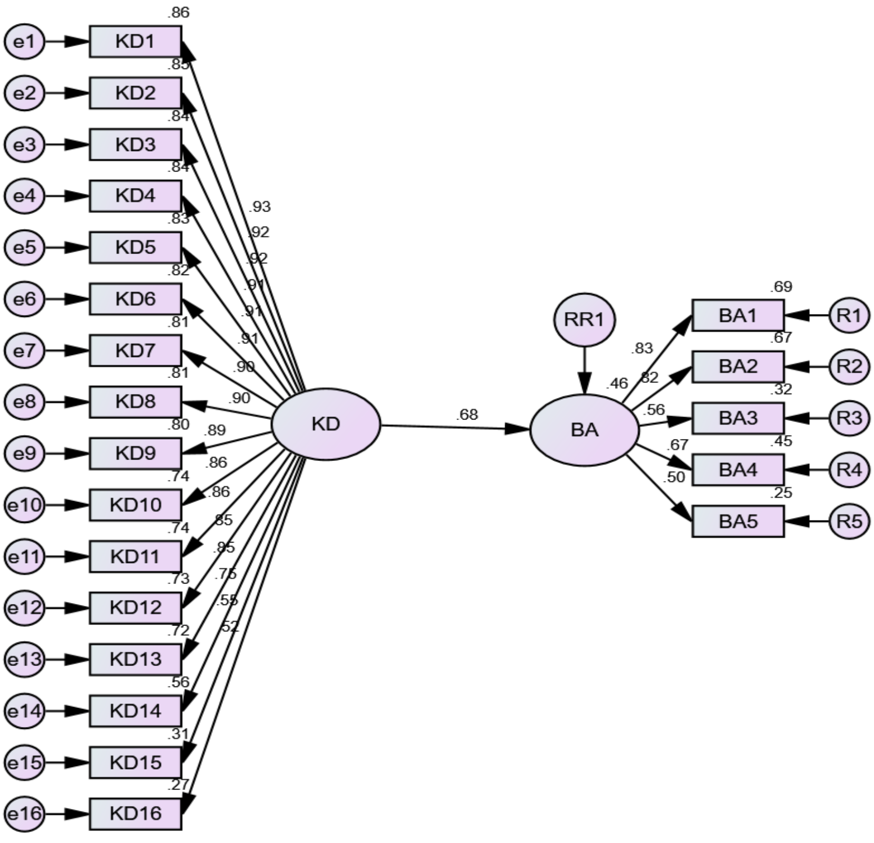

Figure 4. 9 SEM for the effect of Key Drivers (KD) of BIM Adoption Construct on BIM Adoption (BA)

Table 4. 18 presents the correlation coefficients, standard errors, and statistical test results. The standardized coefficient (λ) for the relationship between KD and BA is 0.679, indicating a strong positive association. This suggests that as the key drivers influencing BIM adoption improve, the likelihood of BIM adoption significantly increases.

Table 4. 18 Factor loading and P-value of the effect of Key Drivers (KD) of BIM Adoption Construct on BIM Adoption (BA)

Hypothesized relationships (Path)	Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
BA ← KD	0.654	0.679	0.000	0.560	Yes

KD=Key Drivers, BA = BIM Adoption

The p-value of 0.000 confirms that this relationship is statistically significant at the 5% level, meaning there is strong evidence to support the hypothesis that key drivers play a crucial role in BIM adoption. Additionally, the R-square value of 0.560 implies that 56% of the variance in BIM adoption is explained by the key drivers included in the model. This indicates that the model effectively captures the contribution of KD in predicting BIM adoption, reinforcing the importance of espousing such key drivers to enhance BIM adoption in the construction industry.

4.3.6 Key Barriers Influencing BIM Adoption

Table 4. 19 presents the key barriers influencing BIM adoption and reveals a strong consensus among respondents regarding the significant challenges organizations face. The mean values for all listed items range from 5.44 to 5.81 on a 7-point Likert scale, reflecting substantial agreement across participants. The highest-ranked barrier was “Lack of government regulations to support the implementation of BIM,” which achieved the highest mean score of 5.81, a standard deviation of 1.489, and an RII of 0.830, and was ranked 1st. This highlights the critical need for clear regulatory frameworks to support and encourage BIM adoption.

Financial challenges were also rated among the most significant barriers. “High cost of data to operate cloud-based BIM” (mean = 5.76, RII = 0.823, rank = 2) and “Lack of project funding to support BIM” (mean = 5.74, RII = 0.820, rank = 3) reflect the pressing concern over the cost of BIM set-up. “Lack of a government mandate for BIM implementation” followed closely (mean = 5.73, RII = 0.819, rank = 4), indicating that respondents view both policy and funding limitations as interconnected obstacles.

Organizational and stakeholder resistance emerged as a central theme. “Lack of senior management buy-in” (mean = 5.69, RII = 0.813, rank = 5), “Non-adoption of BIM by other industry professionals”, “Lack of demand and interest from clients”, and “Lack of industry BIM standards and guidelines” each scored a mean of 5.68, shared an RII of 0.811, and were ranked jointly at 6th place. These items reflect significant internal and external resistance to change, pointing to a broader need for industry-wide engagement and awareness-building.

Technical and knowledge-related challenges were also evident. “The initial cost of BIM technology” (mean = 5.66, RII = 0.809, rank = 9) and “Reluctance of project parties to share information” (mean = 5.65, RII = 0.807, rank = 10) highlight infrastructural and collaborative barriers. Issues related to training and awareness, such as “Lack of training courses for industry professionals” and “Limited awareness among organizational leadership” (mean = 5.57, RII = 0.796, rank = 11), further underscore the need for targeted capacity-building initiatives.

Cultural and systemic factors also played a significant role. Items like “The industry's cultural resistance to change,” “Lack of IT infrastructure,” and “Unavailability of BIM risk insurance” all shared the same mean (5.52), RII (0.789), and were ranked 13th, indicating that deeper institutional changes are required to overcome cultural inertia and technical gaps. Moreover, “Lack of case studies demonstrating ROI” and “Lack of standard contracts for BIM ownership and risk assignment” also scored similarly, reinforcing concerns around legal and evidential support for BIM benefits.

Lower-ranked barriers though still significant include “Cost of BIM education and training” and “Low computer skills among construction professionals” (both mean = 5.51, RII = 0.787, rank = 18), and “Lack of skilled professionals with BIM expertise" (mean = 5.44, RII = 0.777, rank = 24). These emphasize the pressing need for technical education and workforce development.

Standard deviation values ranged from 1.352 to 1.604, indicating moderate to high variability. The highest variability was observed for "Low computer skills" (SD = 1.604) and "Data security issues" (SD = 1.599), suggesting divergent respondent experiences with technical capacity and cybersecurity. In contrast, the lowest variability was found in responses to "non-adoption by industry professionals" (SD = 1.353) and "Lack of industry BIM standards" (SD = 1.352), reflecting strong consensus on these barriers.

Table 4. 19 Key Barriers Influencing BIM Adoption

Items	Mean	Std. Dev.	RII	Rank
Lack of government regulations to support the implementation of BIM	5.81	1.489	0.830	**1**
High cost of Data to operate cloud-based BIM	5.76	1.452	0.823	**2**
The lack of project funding to support BIM	5.74	1.484	0.820	**3**
Lack of a government mandate for BIM implementation.	5.73	1.464	0.819	**4**
Lack of senior management buy-in	5.69	1.5	0.813	**5**
Non-adoption of BIM by other industry professionals	5.68	1.353	0.811	**6**
Lack of demand and interest from the clients in the application of BIM in their projects.	5.68	1.494	0.811	**6**
Lack of industry BIM standards and guidelines for implementation	5.68	1.352	0.811	**6**
The initial cost of the technology required for BIM implementation	5.66	1.509	0.809	**9**
The reluctance of other project parties to share information	5.65	1.444	0.807	**10**
Lack of training courses for industry professionals	5.57	1.476	0.796	**11**
Limited awareness among organizational leadership about the potential benefits of BIM.	5.57	1.556	0.796	**11**
The industry's cultural resistance to change	5.52	1.488	0.789	**13**

Items	Mean	Std. Dev.	RII	Rank
Lack of IT infrastructure	5.52	1.441	0.789	**13**
Unavailability of BIM risk insurance	5.52	1.466	0.789	**13**
Lack of case studies that have implemented BIM and realized positive return on investment (ROI)	5.52	1.407	0.789	**13**
Lack of standard contract to deal with responsibility/risk assignment and BIM ownership.	5.52	1.486	0.789	**13**
Cost of BIM education and training	5.51	1.504	0.787	**18**
Low computer skills among construction professionals.	5.51	1.604	0.787	**18**
Lack of awareness of BIM by industry stakeholders	5.5	1.47	0.786	**20**
The steep learning curve to develop BIM expertise	5.48	1.465	0.783	**21**
Data security issues	5.47	1.599	0.781	**22**
Data interoperability challenges between various BIM software.	5.45	1.473	0.779	**23**
The lack of skilled professionals with BIM expertise.	5.44	1.483	0.777	**24**

4.3.6.1 Assessment of the unidimensionality and reliability of the key barriers influencing the adoption of BIM

The EFA was conducted to assess the unidimensionality and reliability of the key barriers influencing the adoption of BIM. PCA Varimax was used as the extraction and rotation method. There were twenty-four items measuring the Construct (see Table A 16, Appendix A). The Kaiser-Meyer-Olkin (KMO) of 0.954 with Bartlett's test of sphericity of $p<0.000$ was obtained, indicating consistency with the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p<0.05$ suggested by Hair et al. (2010). These results confirmed the suitability of the data for factor analysis.

Using a factor loading threshold of 0.5 for factor loading, which is greater than the recommended value of 0.40, as suggested by Field (2005) and Hair Jr. et al. (2021), all items had their factor loading exceeding 0.5 across two identified components.

Fourteen (14) items strongly loaded onto the first component, Institutional and Economic Barriers (IEB). These included: “Lack of government regulations to support the implementation of BIM”, “Lack of a government mandate for BIM implantation”, “Lack of demand and interest from the clients on the application of BIM in their projects”, “High cost of Data to operate cloud-based BIM”, “Lack of training courses for industry professionals”, “The initial cost of the technology required for BIM implementation”, “Lack of IT infrastructure”, “Lack of skilled professionals with BIM expertise”, “The industry's cultural resistance to change”, “Cost of BIM education and training” and “Lack of senior management buy-in”.

The second component, Technical and Operational Barriers (TOB), included ten (10) items with significant loadings: “The steep learning curve to develop BIM expertise”, “Lack of standard contract to deal with responsibility/risk assignment and BIM ownership”, “Unavailability of BIM risk insurance”, “Low computer skills among construction professionals”, “Non-adoption of BIM by other industry professionals”, “Data security issues”, “Lack of industry BIM standards and guidelines for implementation”, “Data interoperability challenges between various BIM software”, “Lack of project funding to support BIM” and “The reluctance of other project parties to share information”.

After using the EFA to extract the component, the corrected item-total correlations were extracted using the recommended cut-off value of 0.30. All items demonstrated strong internal consistency, with Cronbach’s alpha values exceeding 0.800 for each component, indicating acceptable internal reliability (Amron, et al., 2020).

4.3.6.2 SEM for Key Barriers Influencing BIM Adoption Construct

Following the confirmation of unidimensionality and reliability through EFA, a CFA was conducted (Table 4. 20). The analysis strategy for goodness of fit followed a three-statistics approach, using fit indices as recommended by Hu and Bentler (1999). The CFA yielded an S–B$\chi2$ of 9.239 with 251 degrees of freedom (df) and a significant p-value ($p = 0.0000$). This chi-square value indicated that the departure of the sample data from the postulated model was significant and, hence, indicative of a good fit. The chi-square test is very sensitive to sample size and is used more as a descriptive index of fit rather than as a statistical test (Kline, 2005).

The CFI value was 0.928, which is greater than the recommended threshold of 0.90, indicating that the model is considered acceptable. The NFI value was 0.903, which is within the recommended cut-off value of ≥ .90. The PNFI value was 0.783, slightly below the cut-off value of 0.80. Additionally, the RMR was 0.022, less than 0.05, and the GFI value of 0.968 is greater than 0.90.

These fit indices suggest that the proposed Key Barriers Influencing BIM Adoption Construct model adequately describes the sample data and can thus be included in the full latent variable model analysis.

Table 4. 20 Robust Fit Index for Key Barriers Influencing BIM Adoption

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
$S - B\chi^2$		9.239	
Df	0≥	251	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.928	Acceptable
PCFI	Less than 0.80	0.753	Good fit
RMSEA	Less than 0.08	0.021	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.013	Acceptable
NFI	Greater than 0.90 “good fit”	0.911	Good fit
IFI	Greater than 0.90 “good fit”	0.928	Good fit
PNFI	Less than 0.80	0.738	Good fit
RMR	Less than 0.05 “good fit”	0.022	Acceptable
GFI	Greater than 0.90 “good fit”	0.965	Good fit

The unidimensional model for the Key Barriers Influencing BIM Adoption Construct is presented in Figure 4. 10. All twenty-four (24) indicator variables identified were utilized for the final CFA analysis (Jöreskog,1988; Byrne, 2013). From the 380 cases analysed, these indicator variables formed two distinct components: Institutional and Economic Barriers (IEB: IEB1, IEB2, IEB3, IEB4, IEB5, IEB6, IEB7, IEB8, IEB9, IEB10, IEB11, IEB12, IEB13 and IEB14) and Technical and Operational Barriers: (TOB: TOB1, TOB2, TOB3, TOB4, TOB5, TOB6, TOB7, TOB8, TOB9 and TOB10).

All correlation values were below 1.00, and all corresponding p-values were less than the significance threshold of 0.05, indicating statistical significance and confirming appropriate directional relationships (see Appendix A, Table A 18Table A). The parameter estimates are, therefore, considered reasonable and statistically valid. The indicator TOB1 exhibited the highest standardized coefficient of 0.924, indicating its strong relationship within the model.

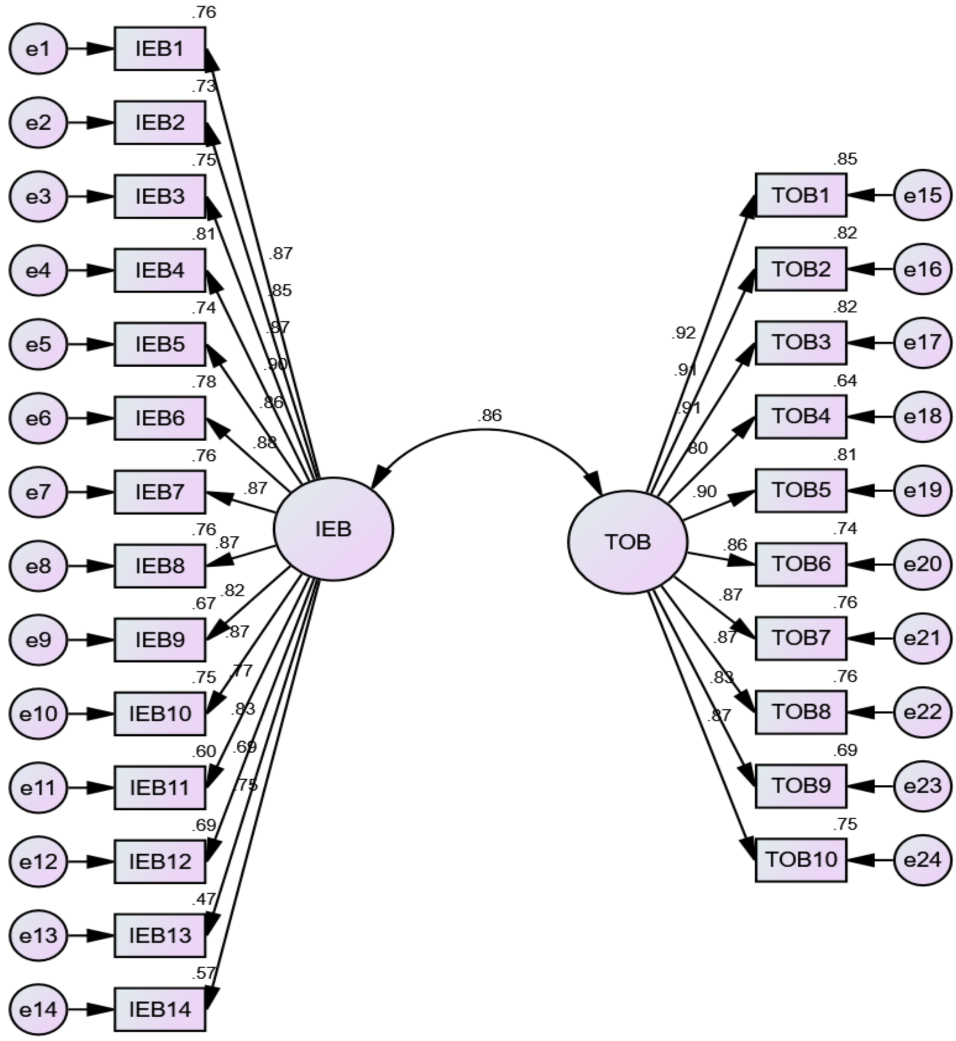

Figure 4. 10 CFA Model for the Key Barriers Influencing BIM Adoption Indicators

4.3.6.3 Testing The Influence of the Identified Barriers to BIM Adoption in Ghana's Construction Industry on the extent of BIM Adoption

SEM in AMOS was used to evaluate the impact of the identified barriers on BIM adoption within Ghana’s construction industry. The analysis produced a Satorra–Bentler Chi-square (S-Bχ^2) value of 8.687 with 375 degrees of freedom (df) and a p-value of 0.0000. Although the significant chi-square value suggests a notable deviation between the sample data and the postulated model, this does not necessarily imply a poor fit within SEM. Instead, it suggests that the model captures meaningful relationships between the constructs under study. The results imply that the proposed model provides a good fit for explaining the impact of barriers on BIM adoption in Ghana’s construction industry.

Moreover, the model fit results indicate that the identified barriers have a significant influence the extent of BIM adoption, highlighting the need for targeted strategies to mitigate these challenges and promote greater BIM adoption within the industry.

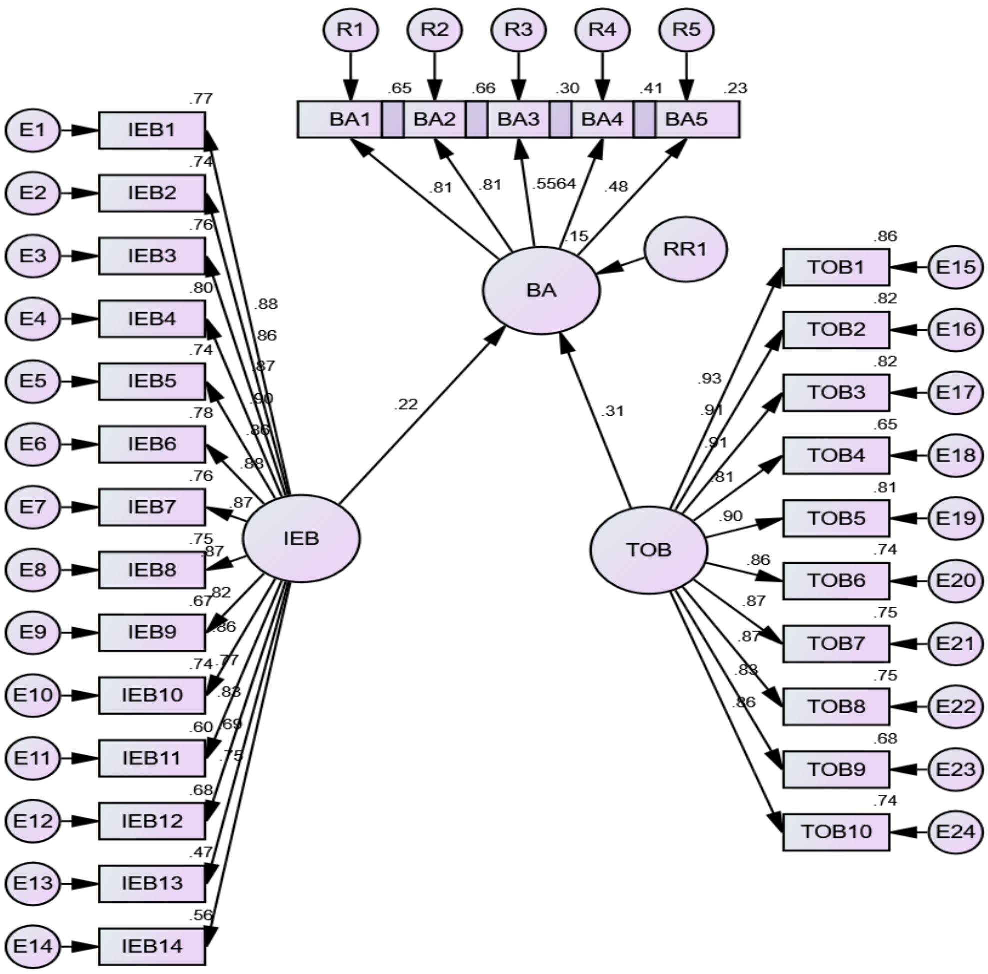

Figure 4. 11 SEM for the Effect of the Identified Barriers to BIM Adoption in Ghana's construction industry on the extent of BIM Adoption

Table 4. 21 presents the correlation coefficients, standard errors and the test of statistics. From the Table, all correlation values are below 1.00, and all p-values are statistically significant at the 5% level ($p < 0.05$). The parameter with the highest standardized coefficient (0.312) was TOB on BA.

Table 4. 21 Factor Loading And P-Value of The Effect of The Identified Barriers to BIM Adoption in Ghana's Construction Industry on The Extent of BIM Adoption

Hypothesized relationships (Path)			Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
BA	←	IEB	0.243	0.220	0.000	0.461	Yes
BA	←	TOB	0.331	0.312	0.000		Yes

Identified Challenges (Technical and Operational Barriers (TOB), and Institutional and Economic Barriers (IEB)) and BIM Adoption

The path coefficient for the relationship between IEB and BA yielded an unstandardized coefficient of 0.243 and a standardized coefficient of 0.220, with a significant p-value of 0.000. This implies that IEB has a significant negative influence on BIM adoption, meaning that challenges such as a lack of government policies, inadequate financial incentives, and institutional resistance significantly hinder BIM adoption within Ghana's construction industry. The R^2 value of 0.461 indicates that IEB explains 46.1% of the variance in BA, underscoring the substantial impact of these barriers on BIM adoption.

Similarly, the path from TOB to BA was statistically significant, producing an unstandardized coefficient of 0.331 and a standardized coefficient of 0.312, with a p-value of 0.000. This result demonstrates that barriers, such as a lack of skilled personnel, software compatibility issues, and inadequate training, significantly impede BIM adoption in the industry. The standardized coefficient (0.312) indicates a strong negative impact on BIM adoption, reinforcing the notion that overcoming technical and operational barriers is crucial for BIM implementation.

The results suggest that IEB and TOB significantly hinder the adoption of BIM in Ghana's construction industry. TOB exhibits a slightly stronger negative influence (0.312) compared to IEB (0.220). This indicates that addressing technical limitations, improving training programs, and ensuring software compatibility may have a greater impact on enhancing BIM adoption than focusing solely on institutional and economic reforms. The significant R^2 value (0.461) suggests that nearly half of the variance in BIM adoption can be attributed to these challenges, demonstrating their substantial role in shaping the adoption process.

4.3.7 Impact of BIM on Construction Project Performance

The analysis presented in Table 4. 22 evaluates the perceived impact of BIM on construction project performance within Ghana's construction industry. The mean scores range from 4.90 to 5.18 on a 7-point Likert scale, reflecting general agreement among respondents regarding the positive influence of BIM across various performance dimensions. The two highest-rated items were "BIM adoption has enhanced coordination among project teams, leading to smoother project execution" and "We have witnessed a significant improvement in tracking change orders throughout our project with the implementation of BIM," both recording a mean of 5.18, RII of 0.740, and ranked jointly at 1st. These results confirm BIM’s crucial role in improving team coordination and managing project changes effectively.

“Improved budget adherence” (mean = 5.10, RII = 0.729, rank = 3) and “Timely completion of projects” (mean = 5.09, RII = 0.727, rank = 4) highlight BIM’s impact on cost control and time management. Likewise, “Optimization of construction sequencing and planning” also scored a mean of 5.09 with an RII of 0.727, reinforcing BIM's operational efficiency benefits. This is further supported by “Improved workflow” (mean = 5.07, RII = 0.724, rank = 6), indicating that respondents attribute smoother project execution to BIM integration.

Quality assurance is also a key area of impact. “Improved quality control measures” (mean = 5.06, RII = 0.723, rank = 7) reflect respondents’ belief that BIM enables early identification of design or coordination issues, helping prevent costly mistakes. Environmental sustainability benefits are also recognized, with “Reduced environmental footprint” (mean = 5.02, RII = 0.717, rank = 8) and “Reduction in site accidents” (mean = 5.00, RII = 0.714, rank = 9) illustrating the broader positive externalities of BIM adoption.

Economic efficiency is acknowledged through “Substantial cost savings” and “Improved accuracy in planning and estimation”, both with mean scores of 4.99, RII = 0.713, and ranked jointly at 10th, showing that BIM contributes to financial savings through efficient workflows and precise forecasting. Energy performance also saw gains, with “Improvements in project energy efficiency” (mean = 4.97, RII = 0.710, rank = 12).

Safety and communication benefits are reflected in “Real-time monitoring of safety conditions” and “BIM-enabled simulations improving stakeholder communication,” both scoring a mean of 4.96, RII = 0.709, and tied at 13th place. These findings suggest that BIM not only enhances technical execution but also supports health, safety, and engagement throughout the project lifecycle.

Further advantages include “Reduction in rework” (mean = 4.95, RII = 0.707, rank = 15) and “Reduction in errors” (mean = 4.94, RII = 0.706, rank = 16), which reinforce BIM’s value in minimizing inefficiencies and promoting accuracy. The lowest-ranked item, though still positively rated, was “BIM-enabled simulations facilitating sustainable material selection" (mean = 4.90, RII = 0.700, rank = 17), indicating that sustainability in material choice, while acknowledged, is perceived as a relatively less prominent benefit compared to other performance indicators. Standard deviation values, ranging from 1.536 to 1.699, indicate moderate variability in responses, suggesting shared but not uniform experiences of BIM benefits across the industry. Notably, coordination, cost control, and safety outcomes showed relatively lower variability, indicating more consistent recognition of these impacts.

Table 4. 22 The Impact of BIM on Construction Project Performance

Items	Mean	Std. Dev.	RII	Rank
BIM adoption has enhanced coordination among project teams, leading to smoother project execution	5.18	1.599	0.740	**1**
We have witnessed a significant improvement in tracking change orders throughout our project with the implementation of BIM	5.18	1.574	0.740	**1**
Our organization has observed improved budget adherence across our projects with the integration of BIM	5.1	1.573	0.729	**3**
The integration of BIM technologies has contributed to the timely completion of projects by our organization	5.09	1.598	0.727	**4**
BIM has played a crucial role in optimizing construction sequencing and planning within our organization	5.09	1.536	0.727	**4**
Our organization has observed an improvement in our workflow due to the implementation of BIM	5.07	1.58	0.724	**6**
BIM has significantly improved our quality control measures, allowing us to detect and address potential issues early in the project lifecycle	5.06	1.656	0.723	**7**

Items	Mean	Std. Dev.	RII	Rank
With the integration of BIM, our organization has made significant strides in reducing our environmental footprint	5.02	1.641	0.717	**8**
Our organization has experienced a notable reduction in accidents on construction sites since implementing	5.00	1.601	0.714	**9**
BIM implementation has led to substantial cost savings for our organization by streamlining work processes	4.99	1.591	0.713	**10**
The utilization of BIM technologies has led to improved accuracy in our project planning and estimation	4.99	1.604	0.713	**10**
Our organization has witnessed tangible improvements in the energy efficiency of our projects through the integration of BIM	4.97	1.601	0.710	**12**
BIM has enabled real-time monitoring of safety conditions during our projects, providing us with invaluable insights to proactively address safety concerns and ensure the well-being of our workforce	4.96	1.63	0.709	**13**
BIM-enabled simulations and visualizations have positively impacted stakeholder communication and understanding of project progress	4.96	1.699	0.709	**13**
Our organization has observed a significant reduction in rework since implementing BIM	4.95	1.651	0.707	**15**
Our organization has witnessed a marked reduction in errors since integrating BIM into our processes	4.94	1.591	0.706	**16**
BIM-enabled simulations have facilitated improved material selection within our organization, allowing us to make more informed choices that prioritize sustainability	4.9	1.629	0.700	**17**

4.3.7.1 Assessment of the unidimensionality and reliability of the Impact of BIM on Construction Project Performance construct

EFA was performed to assess the unidimensionality and reliability of the Impact of BIM on Construction Project Performance construct (see appendix A, Table A 19). PCA with Varimax was specified as the extraction and rotation method. A total of seventeen items were used to measure this construct. The Kaiser-Meyer-Olkin (KMO) was 0.977, and Bartlett's test of sphericity was significant ($p < 0.000$), indicating consistency with the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p < 0.05$ suggested by Hair et al. (2010). These results confirmed the suitability of the data for factor analysis.

All items loaded significantly onto two distinct components using a factor loading threshold of 0.5, which exceeds the recommended value of 0.40 as suggested by Field (2005) and Hair Jr et al. (2021).

The first component, Project Efficiency and Performance Optimization (PEPO), comprised eleven (11) items: "The utilization of BIM technologies has led to improved accuracy in our project planning and estimation", "BIM implementation has led to substantial cost savings for our organization by streamlining work processes", "BIM-enabled simulations and visualizations have positively impacted stakeholder communication and understanding of project progress", "The integration of BIM technologies has contributed to the timely completion of projects by our organization", "Our organization has observed a significant reduction in rework since implementing BIM", "Our organization has observed improved budget adherence across our projects with the integration of BIM", "Our organization has observed an improvement in our workflow due to the implementation of BIM", "BIM has played a crucial role in improving construction sequencing and planning within our organization", "We have witnessed a significant improvement in tracking change orders throughout our project with the implementation of BIM", "Our organization has witnessed a marked reduction in errors since integrating BIM into our processes", and "BIM adoption has enhanced coordination among project teams, leading to smoother project execution."

The second component, Quality Control and Sustainability Enhancements (QCSE) contained six (6) items: "BIM has significantly improved our quality control measures, allowing us to detect and address potential issues early in the project lifecycle", "With the integration of BIM, our organization has made significant strides in reducing our environmental footprint", "Our organization has witnessed tangible improvements in the energy efficiency of our projects through the integration of BIM", "Our organization has experienced a notable reduction in accidents on construction sites since implementing", "BIM has enabled real-time monitoring of safety conditions during our projects, providing us with invaluable insights to proactively address safety concerns and ensure the well-being of our workforce", and "BIM-enabled simulations have facilitated improved material selection within our organization, allowing us to make more informed choices that prioritize sustainability."

After extracting the components, the corrected item-total correlations were evaluated using a cut-off value of 0.30. The items were found to be good measures of the components, as the Cronbach's alphas were all greater than 0.800 for each component, indicating acceptable internal reliability (Amron & Chuprat, 2020).

4.3.7.2 SEM for the Impact of BIM on Construction Project Performance Construct

After the constructs demonstrated sufficient evidence of unidimensionality and reliability using EFA, a CFA was then administered (Table 4. 23). The analysis strategy of goodness of fit for the Impact of BIM on Construction Project Performance Construct followed a three-statistic strategy of fit indexes as recommended by Hu and Bentler (1999). The sample data on the model yielded an S–B$\chi 2$ of 3.538 with 118 degrees of freedom (df), corresponding to a probability of $p = 0.0000$. The chi-square value indicated that the departure of the sample data from the postulated model was significant, indicating a good fit. The chi-square test is very sensitive to sample size and is used more as a descriptive index of fit rather than as a statistical test (Kline, 2005).

The CFI value was 0.967, exceeding the cut-off limit of 0.90, which confirms an acceptable model fit. Similarly, the NFI value was 0.955, which also exceeded the cut-off value of NFI ≥ 0.90, thereby further supporting the model's adequacy. The PNFI value obtained was 0.628, below the cut-off value of 0.80. Additionally, the RMR was 0.028, which is well within the acceptable range (< 0.05), and the

GFI value was 0.979, exceeding the threshold of 0.90. These fit indices suggest that the Impact of the postulated model accurately represents the sample data and is, therefore, suitable for inclusion in the full latent variable model analysis.

Table 4. 23 Robust Fit Index for the Impact of BIM on Construction Project Performance

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
$S - B\chi^2$		3.538	
Df	0≥	118	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.967	Acceptable
PCFI	Less than 0.80	0.457	Good fit
RMSEA	Less than 0.08	0.031	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.030	Acceptable
NFI	Greater than 0.90 “good fit”	0.955	Good fit
IFI	Greater than 0.90 “good fit”	0.968	Good fit
PNFI	Less than 0.80	0.628	Good fit
RMR	Less than 0.05 “good fit”	0.028	Acceptable
GFI	Greater than 0.90 “good fit”	0.979	Good fit

The unidimensional model for the Impact of BIM on Construction Project Performance is presented in Figure 4. 12. All seventeen indicator variables identified were included in the final CFA analysis (Jöreskog,1988; Byrne, 2013). The analysis involved 380 cases, encompassing PEPO (PEPO1 to PEPO11) and QCSE (QCSE1 to QCSE6).

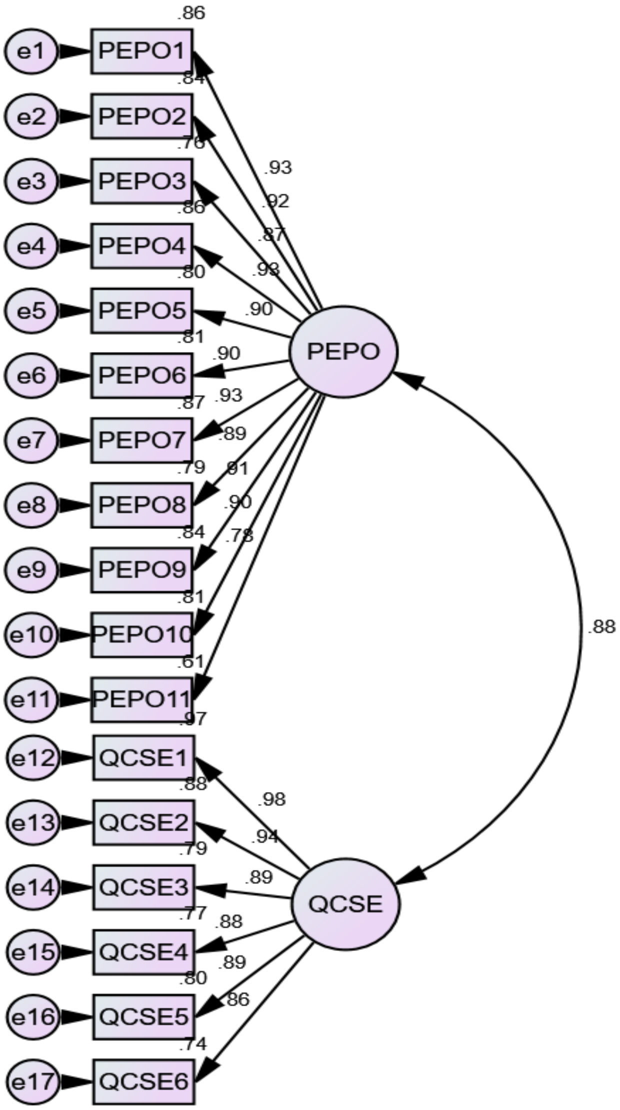

Figure 4. 12 CFA Model for the Impact of BIM on Construction Project Performance Indicators

All correlation values were less than 1.00, and all p-values were statistically significant at the 5% significance level ($p < 0.05$), demonstrating appropriate direction and strength (see Appendix A, Table A 20). Thus, these estimates were considered both reasonable and statistically significant. The indicator QCSE1 exhibited the highest standardized coefficient, with a value of 0.983, highlighting a strong relationship within the model.

4.3.7.3 Testing The Influence of the Adoption of BIM On the Performance of Construction Projects in Ghana

The SEM in AMOS was applied to evaluate the impact of BIM adoption on the performance of construction projects in Ghana (see Ghansah et al., 2024). The analysis yielded a Satorra–Bentler Chi-square (S-Bχ^2) value of 4.634 with 207 degrees of freedom (df) and a p-value of 0.000. While the chi-square result is statistically significant, suggesting a notable discrepancy between the sample data and the hypothesized model, this does not necessarily imply a poor fit in SEM. Instead, it suggests that the model effectively captures the relationships between BIM adoption and construction project performance. These results confirm that the proposed model provides a strong statistical fit, adequately describing the data and supporting the hypothesized relationship between BIM adoption and project performance.

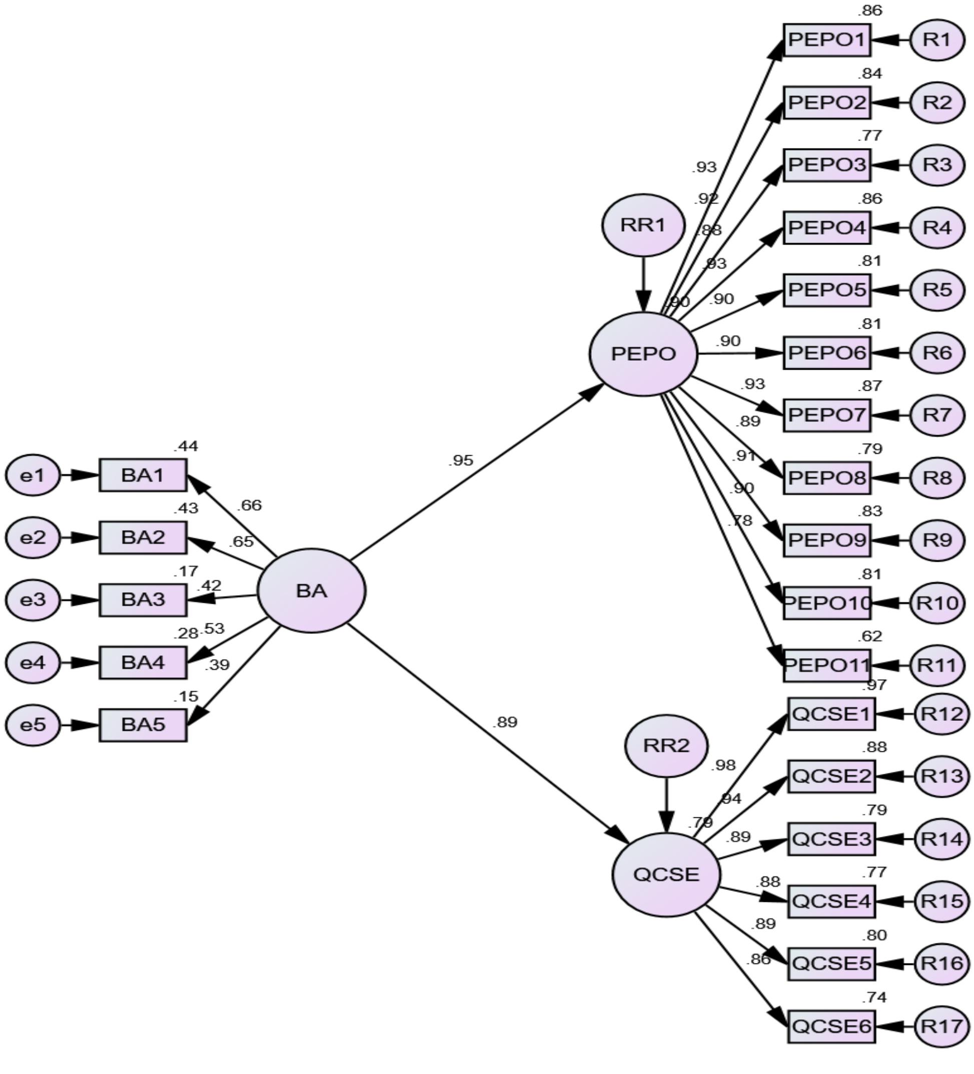

Figure 4. 13 SEM for the effect of the BIM Adoption on the Performance of Construction Projects in Ghana

Table 4. 24 presents the correlation coefficients, standard errors, and statistical test results for the SEM. All correlation values are below the threshold of 1.00, indicating the absence of multicollinearity. Additionally, all p-values were less than 0.05, confirming statistical significance at the 5% level. The path coefficients indicate strong and statistically significant relationships between BIM adoption and various project performance indicators.

Table 4. 24 Factor loading and P-value of the effect of The Adoption of BIM on the Performance of Construction Projects in Ghana

Hypothesized relationships (Path)			Unstandardized Coefficient (λ)	Standardized Coefficient (λ)	P-Value	R-Square	Significant at 5% Level
PEPO	←	BA	1.156	0.948	0.000	0.899	Yes
QCSE	←	BA	1.181	0.887	0.000		Yes

BIM Adoption (BA) on Construction project performance (Project Efficiency and Performance Optimization (PEPO), and Quality Control and Sustainability Enhancements (QCSE))

The path coefficient for the relationship between BIM Adoption (BA) and Project Efficiency and Performance Optimization (PEPO) is 1.156 (unstandardized) and 0.948 (standardized), with a p-value of 0.000, indicating high statistical significance at the 0.05 level. Additionally, the R^2 value of 0.899 for PEPO indicates that BIM adoption explains 89.9% of the variance in project efficiency and performance optimization. This highlights the critical role of BIM adoption in enhancing operational efficiency and improving performance outcomes within Ghana’s construction industry.

Similarly, the relationship between BIM Adoption (BA) and Quality Control and Sustainability Enhancements (QCSE) demonstrated a statistically significant effect, with an unstandardized coefficient of 1.181 and a standardized coefficient of 0.887 (p=0.000). This significant association suggest that BIM adoption substantially improves quality control and sustainability practices, reinforcing BIM’s positive contribution to achieving higher standards in the construction process.

The statistical analysis confirms that BIM adoption has a significant influence on construction project performance in Ghana, particularly in improving efficiency, performance, quality control, and sustainability measures. These outcomes highlight the strategic value of integrating BIM practices into Ghana's construction industry to ensure streamlined operations, reduced inefficiencies, better quality assurance, and enhanced sustainability practices.

4.3.8 Strategies for Effective BIM Adoption

Table 4. 25 reveals a strong consensus among respondents on a range of strategies critical for the effective adoption of BIM within Ghana's construction industry. The mean scores ranged from 5.63 to 5.87 on a 7-point Likert scale, indicating generally high agreement with the proposed strategies. The relatively narrow standard deviation range further suggests moderate variability in the responses.

The most highly rated strategy was "Involving all stakeholders early in the BIM process," which achieved a mean score of 5.87, RII of 0.839, and was ranked 1st. This emphasizes the recognized importance of early engagement to ensure alignment and buy-in. This was followed by "Organizing industry-wide forums, conferences, and seminars on BIM" (mean = 5.86, RII = 0.837, rank = 2) and "Encouraging open collaboration and data sharing among project participants" (mean = 5.85, RII = 0.836, rank = 3), underscoring the vital role of industry awareness, dialogue, and collaborative environments in promoting BIM.

Financial support strategies were also rated highly. Both "Offering financial assistance or subsidies for SMEs" and "Demonstrating the long-term financial benefits of BIM" tied at rank 4 (mean = 5.84, RII = 0.834), highlighting strong belief in the power of economic incentives to drive adoption. Likewise, "Conducting cost-benefit analyses" was ranked 14th (mean = 5.73, RII = 0.819), suggesting that stakeholders value evidence-based justifications to support investment in BIM.

Capacity-building and technological readiness were also considered key. Strategies such as "Industry collaboration with academic institutions" and "Investing in advanced technology infrastructure" both recorded a mean of 5.81 (RII = 0.830, rank = 6), demonstrating that stakeholders view education and infrastructure development as foundational to successful BIM integration. Similarly, "Establishing BIM certification programs" (mean = 5.80, RII = 0.829, rank = 8), “Securing data-sharing platforms” (mean = 5.79, RII = 0.827, rank = 9), and “Upskilling the workforce through hands-on training” (mean = 5.77, RII = 0.824, rank = 10) reinforce the emphasis on preparing a BIM-ready workforce.

Organizational leadership and support also featured prominently. “Senior management's commitment to BIM adoption” (mean = 5.73, RII = 0.819, rank = 14), “Promotion of cross-departmental collaboration” (mean = 5.69, RII = 0.813, rank = 23), and “Allocation of sufficient resources by organizations” (mean = 5.67, RII = 0.810, rank = 26) reflect the view that internal organizational culture, leadership, and resourcing are essential enablers of adoption.

In contrast, systemic and policy-driven strategies were rated slightly lower but still deemed important. “Establishing national BIM standards and guidelines” and “Implementing collaborative procurement models” shared the lowest RII of 0.804, both ranked 28th (mean = 5.63), while “Government-mandated BIM requirements” (mean = 5.68, RII = 0.811, rank = 24) and “Enforceable government regulations” (mean = 5.66, RII = 0.809, rank = 27) also ranked toward the bottom. This suggests that although respondents recognize the importance of a regulatory and contractual framework, they consider stakeholder involvement, capacity building, and technological readiness to be more immediately impactful.

Table 4. 25 Strategies for Effective Adoption of BIM

Items	Mean	Std. Dev.	RII	Rank
Involving all stakeholders early in the BIM process is essential for effective adoption.	5.87	1.326	0.839	**1**
Organizing industry-wide forums, conferences, and seminars on BIM will help share knowledge and best practices for adoption.	5.86	1.363	0.837	**2**
Encouraging open collaboration and data sharing among project participants is critical for effective BIM adoption.	5.85	1.331	0.836	**3**
Offering financial assistance or subsidies for small and medium enterprises (SMEs) to adopt BIM will promote its widespread use.	5.84	1.365	0.834	**4**

Items	Mean	Std. Dev.	RII	Rank
Demonstrating the long-term financial benefits of BIM will encourage adoption.	5.84	1.41	0.834	**4**
Industry collaboration with academic institutions to provide BIM-focused education and training programs will improve BIM readiness.	5.81	1.374	0.830	**6**
Investing in advanced technology infrastructure (hardware, software, and networking) is critical for successful BIM adoption.	5.81	1.403	0.830	**6**
Establishing BIM certification programs for professionals will drive skill development and adoption in the industry.	5.8	1.32	0.829	**8**
Implementing secure and efficient data-sharing platforms is crucial for BIM adoption.	5.79	1.352	0.827	**9**
Upskilling the workforce through hands-on BIM experience and practical training is key to successful implementation.	5.77	1.353	0.824	**10**
Establishing benchmarks and performance metrics for BIM projects will help organizations measure success and improve adoption strategies.	5.76	1.385	0.823	**11**
Conducting regular reviews of BIM project performance and sharing the results with stakeholders will promote continuous improvement.	5.76	1.414	0.823	**11**
Encouraging contractual agreements that foster BIM collaboration between different project teams will drive adoption.	5.74	1.334	0.820	**13**
Senior management's commitment to BIM adoption is key to ensuring a successful implementation strategy.	5.73	1.409	0.819	**14**
Adopting risk-sharing frameworks for BIM projects will encourage organizations to implement the technology.	5.73	1.349	0.819	**14**

Items	Mean	Std. Dev.	RII	Rank
Conducting thorough cost-benefit analyses for BIM adoption in projects as a way of demonstrating its value to stakeholders.	5.73	1.376	0.819	**14**
Government support and incentives are crucial for effective BIM adoption	5.71	1.612	0.816	**17**
Fostering a culture of innovation within organizations is important for encouraging BIM adoption.	5.71	1.332	0.816	**17**
Including BIM-specific clauses in construction contracts to address liabilities and responsibilities will streamline adoption.	5.71	1.43	0.816	**17**
Establishment of clear strategic vision and roadmap for BIM integration is essential for successful adoption.	5.71	1.449	0.816	**17**
Ensuring interoperability between different BIM software platforms is essential for seamless collaboration on projects.	5.71	1.43	0.816	**17**
Ensuring legal frameworks are in place to handle intellectual property and data ownership issues related to BIM models.	5.71	1.445	0.816	**17**
Promotion of cross-departmental collaboration within organizations is key to the success of BIM adoption.	5.69	1.356	0.813	**23**
Developing standardized BIM contract terms and conditions will facilitate smoother adoption.	5.68	1.446	0.811	**24**
Government-mandated BIM requirements for public funded projects will drive BIM adoption in the construction industry.	5.68	1.409	0.811	**24**
Allocation of sufficient resources by organizations towards BIM implementation is a critical	5.67	1.443	0.810	**26**
Enforceable government regulations on BIM usage will encourage broader adoption across the construction industry.	5.66	1.555	0.809	**27**

Items	Mean	Std. Dev.	RII	Rank
Establishing national BIM standards and guidelines is essential for ensuring consistency in BIM implementation.	5.63	1.567	0.804	**28**
Implementing collaborative procurement models will support BIM adoption by improving coordination among stakeholders.	5.63	1.316	0.804	**28**

4.3.8.1 Assessment of the unidimensionality and reliability of the Strategies for the Effective Adoption of BIM construct

The EFA was conducted to assess the unidimensionality and reliability of the Strategies for the Effective Adoption of BIM construct. PCA Varimax was used as the extraction and rotation method for twenty-nine items measuring the Construct (Table A 21, Appendix A). The Kaiser-Meyer-Olkin (KMO) was 30.971, and Bartlett's test of sphericity was significant ($p < 0.000$) surpassing the recommended KMO cut-off value of 0.70 and Bartlett's test of sphericity of $p < 0.05$ suggested by Hair et al. (2010). These results confirmed the appropriateness of the data for factor analysis.

A factor loading threshold of 0.5 was applied, which is above the recommended value of 0.40 by Field (2005) and Hair Jr. et al. (2021); all items exhibited factor loadings exceeding 0.5. This resulted in them being loaded onto three (3) distinct components.

The first component, Organizational and Collaborative Strategies (OCS), consisted of fifteen (15) items: "Conducting thorough cost-benefit analyses for BIM adoption in projects as a way of demonstrating its value to stakeholders", "Developing standardized BIM contract terms and conditions will facilitate smoother adoption", 'Demonstrating the long-term financial benefits of BIM will encourage adoption", "Involving all stakeholders early in the BIM process is essential for effective adoption", "Including BIM-specific clauses in construction contracts to address liabilities and responsibilities will streamline adoption", "Establishing benchmarks and performance metrics for BIM projects will help organizations measure success and improve adoption strategies", "Implementing collaborative procurement models will support BIM adoption by improving coordination among stakeholders", "Ensuring legal frameworks are in place to handle intellectual property and data ownership issues related to BIM models", "Adopting risk-sharing frameworks for BIM projects will encourage organizations to implement the technology", "Encouraging contractual agreements that foster BIM collaboration between different project teams will drive adoption", "Offering financial assistance or subsidies for small and medium enterprises (SMEs) to adopt BIM will promote its widespread use", "Conducting regular reviews of BIM project performance and sharing the results with stakeholders will promote continuous improvement", "Organizing industry-wide forums, conferences, and seminars on BIM will help share knowledge and best practices for adoption", "Encouraging open collaboration and data sharing among project participants is critical for effective BIM adoption", and "Upskilling the workforce through hands-on BIM experience and practical training is key to successful implementation".

The second component, Technological and Managerial Strategies (TMS), comprised ten (10) items: "Investing in advanced technology infrastructure (hardware, software, and networking) is critical for successful BIM adoption", "Fostering a culture of innovation within organizations is important for encouraging BIM adoption", "Industry collaboration with academic institutions to provide BIM-focused education and training programs will improve BIM readiness", "Ensuring interoperability between different BIM software platforms is essential for seamless collaboration on projects", "Implementing secure and efficient data-sharing platforms is crucial for BIM adoption", "Promotion of cross-departmental collaboration within organizations is key to the success of BIM adoption", "Establishing BIM certification programs for professionals will drive skill development and adoption in the industry", "Allocation of sufficient resources by organizations towards BIM implementation is a critical", "Establishment of clear strategic vision and roadmap for BIM integration is essential for successful adoption" and "Senior management's commitment to BIM adoption is key to ensuring a successful implementation strategy".

The third component, Policy and Regulatory Strategies (PRS) included four (4) items. They are "Government support and incentives are crucial for effective

BIM adoption", "Enforceable government regulations on BIM usage will encourage broader adoption across the construction industry", "Establishing national BIM standards and guidelines is essential for ensuring consistency in BIM implementation" and "Government-mandated BIM requirements for public funded projects will drive BIM adoption in the construction industry".

Following component extraction, corrected item-total correlations were calculated using the suggested cut-off value of 0.30. All components showed Cronbach's alpha values exceeding 0.800, indicating acceptable internal reliability (Amron, Ibrahim, Bakar & Chuprat, 2020).

4.3.8.2 SEM for the Strategies for Effective Adoption of BIM Construct

After the constructs demonstrated sufficient evidence of unidimensionality and reliability using EFA, a CFA was then conducted for the construct. The goodness-of-fit analysis followed a three-statistics strategy recommended by Hu and Bentler (1999). The sample data on the model yielded the S–Bχ2 of 5.959 with 347 degrees of freedom (df) and a significant p-value of 0.0000 (Table 4. 26). This chi-square value indicated that the departure of the sample data from the postulated model was significant and, hence, indicative of a good fit. The chi-square test is sensitive to sample size and is used more as a descriptive index of fit rather than as a statistical test (Kline, 2005).

The CFI value was 0.925, greater than the cut-off limit of 0.90; this indicates an acceptable model fit. The NFI value of 0.900 met the minimum recommended cut-off value of NFI $\geq$ .90. The PNFI value of 0.714, below the cut-off value of 0.80, is acceptable. Additionally, the RMR value was 0.031, well below the recommended maximum of 0.05, and the GFI value was 0.927, exceeding the acceptable threshold of 0.90.

These fit indices indicate that the proposed Strategies for Effective Adoption of BIM Construct model adequately describes the sample data, making it suitable for inclusion in the full latent variable model analysis.

Table 4. 26 Robust Fit Index for the Strategies for Effective Adoption of BIM

Fit Index	**Cut-Off Value**	**Estimate**	**Comment**
S – Bχ^2		5.959	
Df	0≥	374	Acceptable
CFI	0.90≥ acceptable 0.95≥ good fit	0.925	Acceptable
PCFI	Less than 0.80	0.630	Good fit
RMSEA	Less than 0.08	0.018	Acceptable
RMSEA 95% CI	0.00-0.08 “good fit”	0.000-0.017	Acceptable
NFI	Greater than 0.90 “good fit”	0.911	Good fit
IFI	Greater than 0.90 “good fit”	0.906	Good fit
PNFI	Less than 0.80	0.714	Good fit
RMR	Less than 0.05 “good fit”	0.031	Acceptable
GFI	Greater than 0.90 “good fit”	0.927	Good fit

The unidimensional model for the Strategies for Effective Adoption of BIM Construct features is presented in Figure 4. 14. All twenty-nine (29) identified indicator variables were obtained and used for the final CFA analysis (Jöreskog,1988; Byrne, 2013). From the 380 cases analysed, these indicators formed three (3) distinct components realised as OCS (OCS1, OCS2, OCS3, OCS4, OCS5, OCS6, OCS7, OCS8, OCS9, OCS10, OCS11, OCS12, OCS13, OCS14 and OCS15), TMS (TMS1, TMS2, TMS3, TMS4, TMS5, TMS6, TMS7, TMS8, TMS9 and TMS10) and PRS (PRS1, PRS2, PRS3 and PRS4).

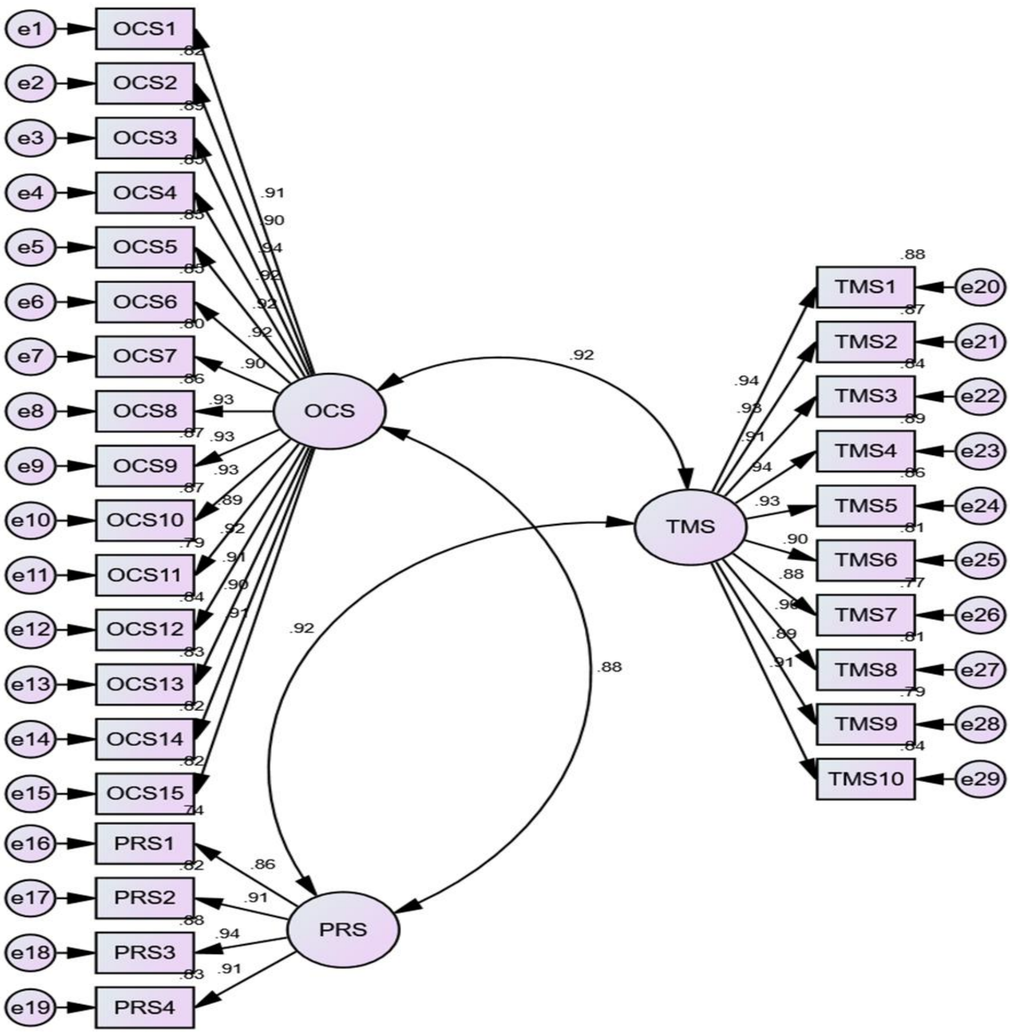

Figure 4. 14 CFA Model for the Strategies for Effective Adoption of BIM Indicators

All correlation values were less than 1.00, and all corresponding p-values were less than the significance value of 0.05 and showed appropriate directional relationships (see Appendix A, Table A 23). The parameter estimates are deemed reasonable and statistically valid. The OCS3 indicator exhibited the highest standardized coefficient, with a value of 0.942, indicating a strong association within the model. Most parameter estimates exhibited high correlation values close to 1.00, indicating strong linear relationships between the indicator variables and the latent factors within the construct. Additionally, the R Square values were close to the desired value of 1.00, indicating that the latent factors explained more of the variance in the indicator variables. The results suggest that the indicator variables significantly predict their respective latent components.