FinTech

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Codify, Condition, Capacitate: Expert Perspectives on Institution-First Blockchain–BIM Governance for PPP Transparency in Nigeria

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Abstract

Road infrastructure underpins Nigeria's economic competitiveness, yet Public–Private Partnership (PPP) performance is constrained not by inadequate legislation but by persistent weaknesses in enforcement and governance. Transparency deficits across procurement, design management, certification, and toll-revenue reporting have produced chronic delays, cost overruns, and declining public trust. This study offers the first empirical investigation of blockchain–Building Information Modelling (BIM) integration as a transparency-enhancing mechanism within Nigeria's PPP road sector, focusing on Lagos State. Using a qualitative design, ten semi-structured interviews with stakeholders across the PPP lifecycle were thematically analysed to diagnose systemic governance weaknesses and assess the contextual feasibility of digital innovations. Findings reveal entrenched opacity rooted in weak enforcement, discretionary decision-making, and informal communication practices—including biased bidder evaluations, undocumented design alterations, manipulated certifications, and toll-revenue inconsistencies. While respondents recognised BIM's potential to centralise project information and blockchain's capacity for immutable records and smart-contract automation, they consistently emphasised that technological benefits cannot be realised absent credible institutional foundations. The study advances an original theoretical contribution: the Codify–Condition–Capacitate framework, which explains the institutional preconditions under which digital governance tools can improve transparency. This framework argues that effectiveness depends on: codifying digital standards and legal recognition; conditioning enforcement mechanisms to reduce discretionary authority; and capacitating institutions through targeted training and phased pilots. The research generates significant practical implications for policymakers in Nigeria and comparable developing contexts seeking institution-aligned digital transformation. Methodological rigour was ensured through purposive sampling, thematic saturation assessment, and documented analytical trails.

Keywords: blockchain; building information modelling; infrastructure governance; public–private partnerships; transparency

JEL Classification: H57; O33; D73; G23; O55

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Academic Editors: Andrea Vitaletti and Shyan-Ming Yuan

Received: 28 October 2025
Revised: 13 January 2026
Accepted: 14 January 2026
Published: 16 January 2026

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1. Introduction

Road infrastructure is a fundamental driver of socio-economic development, facilitating mobility, trade, and regional integration across nations [1]. Well-functioning road networks not only enhance the movement of goods and services but also improve access to healthcare, education, and employment, thereby promoting inclusive and sustainable growth [1,2]. Empirical research consistently links road quality and density with productivity, competitiveness, and logistics performance, particularly in developing economies where road transport remains dominant [1,3]. In Nigeria, over 90% of passenger and freight movement depends on roads, underscoring the sector's strategic importance [4]. Yet the nation's road network remains severely underperforming approximately 70% of the 200,000 km network is unpaved or in poor condition, while major highways experience persistent congestion, deterioration, and safety hazards [5]. These deficits increase travel times, heighten vehicle operating costs, restrict market access, and weaken national competitiveness [6,7]. With road quality rated at 2.5/7, far below the global average of 4.1, Nigeria's infrastructure gap remains a major developmental constraint [8].

To close this gap, the Nigerian government has increasingly relied on Public–Private Partnerships (PPPs) as an alternative delivery and financing mechanism [9]. PPPs theoretically offer efficiency gains by leveraging private expertise, capital, and innovation [10,11]. However, Nigeria's PPP experience has been marred by weak governance, opaque procurement processes, and allegations of corruption [12,13]. High-profile road projects such as the Lekki–Epe Expressway and Lagos–Badagry Expressway have suffered from delays, cost overruns, non-transparent concession terms, and public dissatisfaction [14,15]. These challenges reflect deeper structural issues, including information asymmetry, weak monitoring systems, limited stakeholder participation, and governance failures commonly theorised through the Principal–Agent (PA) problem, where the public sector (principal) lacks adequate oversight of private contractors (agents). Studies also highlight deficits in transparency, accountability, and data integrity, issues central to Transparency and Governance Theory, which undermine the legitimacy and long-term sustainability of PPPs [16].

In response to these global governance challenges, digital technologies such as Building Information Modelling (BIM) and Blockchain have been identified as promising innovations for improving transparency, data traceability, and accountability in infrastructure delivery [17]. BIM enables integrated, multi-dimensional project information environments that improve collaboration and reduce discrepancies across project stakeholders [18]. Blockchain provides immutable, decentralized audit trails capable of reducing corruption risks, securing documentation, and automating compliance through smart contracts [19,20]. International studies demonstrate that combining BIM with Blockchain strengthens data trustworthiness, reduces information asymmetry, and enhances procurement transparency in public infrastructure [21]. Unlike single-technology applications, the convergence of BIM and blockchain creates a closed-loop accountability system, where BIM validates and structures project information while blockchain secures, timestamps, and preserves each data output, ensuring both accuracy and immutability across the PPP lifecycle [22,23]. For example, in Singapore, Blockchain-enabled smart contracts to have been integrated with BIM systems to automate payments upon verified milestone completions, reducing disputes and delays [22,23]. This convergence directly addresses theoretical concerns around agency conflicts, information asymmetry, and institutional trust within PPP governance.

Despite this potential, Nigeria remains significantly behind global trends. BIM adoption is fragmented and largely confined to isolated private-sector use, with minimal integration into public infrastructure governance [24]. Blockchain experimentation in the built environment is almost non-existent, constrained by weak institutional frameworks, lack of regulatory certainty, insufficient technical expertise, and infrastructural limitations such as

unreliable internet connectivity and inconsistent power supply [25,26]. The Lagos–Badagry Expressway exemplifies the consequences: prolonged delays, transparency deficits, and public distrust persist despite the state's economic significance and its reliance on PPPs as a development strategy [15,19]. Although global scholarship increasingly examines Blockchain–BIM integration for construction governance, there is no empirical research exploring their combined application within PPP road projects in developing countries, particularly Nigeria. Existing literature is predominantly conceptual and largely based on high-capacity institutional contexts such as the United Kingdom (UK), Singapore, and the Netherlands, conditions that differ markedly from Nigeria's governance environment. As a result, there is limited theoretical and empirical understanding of how Blockchain–BIM integration could address Nigeria-specific transparency and accountability issues [25,27], what contextual barriers may affect implementation, and how such technologies can be aligned with PPP governance frameworks in low-trust environments [5,28]. To address these gaps, this study is guided by the following research questions:

- Research Question 1 (RQ1): What key transparency and accountability challenges affect PPP-funded road development projects in Lagos State?
- Research Question 2 (RQ2): How can Blockchain–BIM integration enhances transparency, data integrity, and accountability in Nigeria's PPP road construction sector?
- Research Question 3 (RQ3): What context-specific strategies are required to enable the effective implementation of Blockchain–BIM solutions within PPP governance structures?

Empirically, this study offers the first evidence from Nigeria examining the feasibility, challenges, and potential of combining Blockchain and BIM to improve governance in road infrastructure PPPs, an area largely overlooked in existing research. Practically, the study develops context-specific implementation strategies tailored to Lagos State's institutional, technical, and regulatory landscape, thereby providing actionable guidance for policymakers, private investors, and construction professionals seeking to enhance transparency and accountability in similar developing-country settings.

1.1. Motivation

The motivation for this research stems from the recognition that technological solutions cannot be imported wholesale from advanced economies without understanding the institutional preconditions necessary for their effectiveness. By investigating how blockchain–BIM integration might function within Lagos State's PPP Road projects—characterised by weak enforcement, fragmented documentation, and political interference—this study responds to calls for context-sensitive research that bridges digital governance theory with the realities of developing-country implementation.

1.2. Research Contributions

This study makes three distinct original contributions to knowledge. First, it provides the first empirical investigation of BIM–blockchain integration for PPP governance in a developing-country context, addressing a significant gap in scholarship that has been predominantly confined to high-capacity institutional environments. Second, the study advances an original theoretical framework—the Codify–Condition–Capacitate model—that explains the institutional preconditions under which digital governance tools can improve transparency, challenging the technology-first assumptions prevalent in construction informatics literature. Third, the study generates significant practical implications by identifying context-specific implementation strategies that can inform policy reform in Nigeria and comparable developing economies. These contributions are elaborated fully in Section 5.7, following the presentation of empirical findings.

Accordingly, the remainder of this paper is structured as follows: Section 2 reviews the relevant theoretical and empirical literature; Section 3 outlines the methodology; Section 4 presents the findings from expert interviews; Section 5 discusses the implications for theory and practice; and Section 6 concludes with recommendations for enhancing transparency in Nigeria's PPP road construction sector.

2. Literature Review

2.1. Theoretical Foundations for PPP Transparency and Digital Governance

The governance challenges that undermine Public–Private Partnership (PPP) road projects are best understood through an integrated theoretical lens combining Principal–Agent Theory, Transparency and Accountability Theory, and Institutional Theory. Together, these frameworks explain not only *why* transparency deficits persist across PPP lifecycles but also *how* digital technologies such as Building Information Modelling (BIM) and blockchain could strengthen governance, conditional on the institutional environment in which they operate.

Principal–Agent (PA) Theory provides the foundational explanation for governance failures in PPPs, highlighting the structural information asymmetry between governments (principals) and private concessionaires (agents) [29]. Because agents often possess superior technical knowledge and substantial operational discretion, principals struggle to detect hidden actions, enforce compliance, or verify claims of performance [25]. This asymmetry manifests in biased bidder evaluations, undocumented design modifications, manipulated certifications, and strategic renegotiations observed in many PPP contexts [30,31]. BIM and blockchain directly address these PA challenges: BIM reduces information asymmetry by creating a common data environment in which design changes, schedules, and cost updates are visible to all actors, while blockchain ensures that once this information is recorded, it cannot be altered without detection [17,32]. When combined, BIM's real-time data validation and blockchain's immutable audit trails create a "closed loop" accountability system that limits opportunistic behaviour.

Transparency and Accountability Theory further extend this perspective by emphasising the centrality of accurate, accessible, and verifiable information for public oversight and trust [33]. PPPs depend on long-term citizen engagement and political legitimacy; thus, transparency in procurement, contract amendments, and performance reporting is essential [34]. BIM contributes to transparency by offering real-time visibility into project progress and enabling traceable design or construction decisions [35], whereas blockchain strengthens accountability by providing tamper-proof audit trails and enabling smart contracts that automatically enforce compliance once agreed conditions are met [32]. Together, these tools offer the potential for continuous accountability, though scholars caution that digital reporting may devolve into "dashboard formalism" if not grounded in substantive monitoring practices [17,32].

Institutional Theory provides the final and most critical dimension by recognizing that technological tools do not produce governance improvements in isolation; rather, their effectiveness depends on the rules, norms, and capacities that shape organizational behavior [36]. High-capacity contexts such as Singapore and the United Kingdom benefit from strong enforcement mechanisms, mandatory digital standards, and mature ICT ecosystems that enable BIM–blockchain integration to function as intended [37–40]. In contrast, Nigeria's weak regulatory enforcement, discretionary decision-making, fragmented documentation systems, and political interference limit the uptake and effectiveness of digital tools [40]. Thus, while BIM and blockchain have significant theoretical potential for improving PPP governance, Institutional Theory underscores that their success ultimately depends on the strength of the institutional foundations that support them.

Drawing on this integrated theoretical framework, three propositions guide the empirical inquiry: Proposition 1: Transparency deficits in Nigerian PPP road projects manifest as principal–agent failures characterized by information asymmetry, hidden actions, and inadequate monitoring capacity. Proposition 2: BIM–blockchain integration has the potential to reduce information asymmetry and strengthen accountability, conditional on the institutional environment in which these tools are deployed. Proposition 3: The effectiveness of digital governance tools is mediated by institutional factors including regulatory codification, enforcement capacity, and professional capability. These propositions are not hypotheses to be statistically tested but theoretical anchors that structure the qualitative inquiry and are explored through the empirical evidence.

2.2. PPP Transparency Issues

Public–Private Partnerships were originally promoted as mechanisms for mobilizing private capital, managerial efficiency, and technological innovation in public infrastructure delivery [41,42]. However, evidence from institutional economics and principal–agent theory demonstrates that the performance of PPPs is heavily dependent on the strength of the institutional environment governing them. Effective PPP governance requires clear rules, credible enforcement, and mechanisms that limit information asymmetry between governments, private actors, and citizens [28]. Where these institutional safeguards are weak, PPPs become vulnerable to opportunistic behaviour, rent seeking, and frequent renegotiation [43].

Globally, the empirical record of PPP outcomes is mixed [44]. While many projects have been completed on schedule, weak oversight has frequently resulted in higher long-term costs, opaque procurement decisions, and contract amendments that undermine public value [42]. In the UK, for example, the National Audit Office found that although 69% of Private Finance Initiative (PFI) projects were delivered on time, PF2 school projects incurred lifecycle costs approximately 40% higher than comparable publicly financed schemes [45], a classic manifestation of principal–agent misalignment. Similar patterns appear in emerging economies: in Brazil, nearly half of PPP contracts were renegotiated within five years due to regulatory shortcomings [46], and India's National Highway Development Project experienced 35% cost overruns, largely driven by institutional bottlenecks in land acquisition and stakeholder coordination [2]. Collectively, these cases underscore a central theoretical insight: PPP governance deteriorates when the institutional capacity to monitor, enforce, and disclose project information is insufficient.

In Nigeria, transparency challenges are deeper and more systemic. Reports by the Infrastructure Concession Regulatory Commission show that roughly 70% of PPP projects in the road and energy sectors suffer from procurement-related irregularities and weak accountability structures [47]. Empirical studies highlight recurring governance failures, including political interference, incomplete documentation, and the prequalification of politically connected yet technically unqualified firms [16,40,48]. The Lekki–Epe Expressway and the Lagos–Badagry Expressway illustrate these conditions vividly, with non-transparent concession terms, prolonged delays, and inconsistent public disclosure [48], further exposing structural deficiencies in institutional oversight [15].

The consequences are far-reaching. Persistent opacity not only leads to inflated costs and delivery delays but also erodes public trust and reinforces perceptions of corruption [9,34]. Evidence from Lagos PPPs indicates that procurement and contract management frequently rely on informal channels, emails, messaging applications, or undocumented meetings, thereby creating opportunities for selective disclosure and data manipulation [9]. In contrast, advanced economies employ formalized digital disclosure mandates, such as the UK's open procurement laws and Singapore's statutory reporting requirements [37,49],

which limit discretionary practices and enhance public scrutiny. Nigeria, however, lacks a comparable regulatory framework for digital record-keeping or real-time PPP monitoring, widening opportunities for rent-seeking behaviour [47].

While international case studies provide useful lessons, their applicability to Nigeria is constrained. Policy diffusion theory cautions that governance models cannot be seamlessly transplanted into contexts with divergent political, cultural, and administrative structures [15,43]. The success of PPP reforms in countries such as Singapore is underpinned by strong rule enforcement, high bureaucratic capacity, and mature digital infrastructure, conditions that diverge sharply from Nigeria's fragmented institutional landscape. Likewise, the UK's transparency mechanisms rely on well-established audit institutions and statutory disclosure frameworks that are not yet mirrored in Nigeria [35,50]. Thus, Nigeria's PPP shortcomings should not be interpreted merely as operational failures but as products of deeper institutional weaknesses that require context-specific governance solutions rather than direct replication of external models.

Therefore, the literature demonstrates that while robust governance structures are essential for PPP success globally, Nigeria's persistent institutional deficiencies, limited enforcement capacity, informal decision-making, and inadequate digitalization, pose significant barriers to transparency and accountability. Without targeted regulatory reforms and systematic digital transformation, PPP road projects, responsible for over 90% of national freight and passenger movement, are likely to continue underperforming [4,47].

2.3. Integration of Blockchain and BIM

Blockchain and Building Information Modelling have emerged as leading digital innovations capable of strengthening transparency and accountability in infrastructure delivery. Blockchain's decentralized and immutable ledger enables tamper-proof, auditable records of transactions and decisions, significantly reducing opportunities for document manipulation or selective disclosure in construction processes [51]. Its application to procurement monitoring, supply-chain verification, and contract execution has demonstrated strong potential for improving governance in public projects [52]. A key feature is the smart contract, which automatically triggers actions, such as milestone payments, once predefined conditions are verified, thereby reducing discretion and lowering corruption risks [53]. International pilots in the UK, Singapore, and the Netherlands show that blockchain-enabled systems have improved milestone verification, payment tracking, and compliance reporting, while reducing disputes and administrative delays [54,55].

BIM, meanwhile, provides a shared digital project environment in which stakeholders can access coordinated information across design, construction, and operations [56]. Its Common Data Environment (CDE) improves accuracy, reduces design conflicts, and supports real-time oversight of project progress, cost changes, and design revisions [57]. Increasingly, scholars emphasize BIM's governance value: by generating version-controlled records and transparent audit trails, BIM enhances accountability in project delivery and reduces information asymmetry among PPP stakeholders [58,59].

The combined use of BIM and blockchain offers a more robust governance solution than either technology alone. BIM structures and validates project data, while blockchain secures these records through immutable timestamps and cryptographic protection. Together, they create a "closed-loop accountability system" in which data entered BIM cannot be altered without detection once committed to the blockchain. This integration reduces information asymmetry, increases trust among stakeholders, and enhances compliance in long-term PPP arrangements, benefits documented in early pilot projects in Europe and Asia.

Despite this potential, BIM adoption in Nigeria remains partial and inconsistent. Empirical studies indicate that usage is largely limited to basic 3D modelling, with limited deployment of advanced 4D (time) and 5D (cost) capabilities [60]. BIM is seldom integrated into PPP governance frameworks and lacks national regulatory backing. Nigeria's reliance on paper-based workflows, fragmented procurement processes, and voluntary digital adoption has undermined BIM's capacity to contribute meaningfully to transparency [40]. Awareness campaigns by professional bodies have increased visibility but have not translated into systematic institutional uptake [24]. Blockchain adoption is even more limited; although recognized conceptually as a tool for combating corruption, its application in Nigeria remains virtually non-existent due to infrastructural constraints, unclear legal recognition of digital records, and inadequate technical skills [25].

Table 1 highlights critical disparities between Nigeria and more digitally mature countries, showing gaps in national BIM standards, blockchain regulation, digital infrastructure, and institutional capacity. While Singapore, the UK, and the Netherlands benefit from strong digital ecosystems and robust enforcement mechanisms, Nigeria's weak institutional environment limits the feasibility of deploying integrated digital governance tools at scale. Yet, the severity of Nigeria's PPP transparency problems renders BIM–blockchain integration particularly relevant as a reform pathway. Crucially, no empirical research has examined how such integration could operate within Nigeria's low-trust, resource-constrained context, underscoring a significant gap that this study seeks to address.

Table 1. Comparative Readiness for BIM–Blockchain Adoption in PPP Infrastructure Governance.

Dimension	Nigeria	Singapore	UK	Netherlands
National BIM Standards	None; fragmented voluntary adoption	Mandatory BIM roadmap (2015); nationwide adoption	BIM Level 2 mandatory since 2016	National BIM programme active; strong standardization
Blockchain Policy Framework	No legal recognition for blockchain records; no construction pilots	Government-led blockchain strategy; multiple public-sector pilots	Regulatory sandbox for blockchain applications	Active experimentation in public infrastructure and logistics
Digital Infrastructure	Weak (unreliable power, poor internet penetration)	High digital connectivity; strong Information Communication Technology (ICT) backbone	High; widespread digital integration across government	High; strong e-governance environment
PPP Transparency Frameworks	Paper-based, discretionary enforcement	Mandatory disclosure, independent oversight	Open procurement laws; audit transparency	Strong compliance culture; digital public services
BIM–Blockchain Pilot Projects	None in construction or PPPs	Integrated BIM–blockchain payment validation in public works	Pilots in procurement tracking and design audit trails	Pilots in asset management and logistics transparency
Institutional Capacity	Limited digital skills; weak monitoring capacity	Strong technical capability; continuous upskilling	Mature digital construction ecosystem	High institutional readiness
Governance Culture	Informal communication; high discretion; low trust	High compliance; low tolerance for manipulation	Strong accountability culture	Strong procedural discipline

2.4. Theoretical and Empirical Limitations in PPP Digital Governance

Although global scholarship has increasingly explored the potential of digital technologies to strengthen governance in infrastructure delivery, the literature reveals several unresolved theoretical and empirical gaps that limit understanding of how transparency can be improved in Public–Private Partnership road projects, particularly in developing institutional contexts such as Nigeria.

First, existing studies from the UK, Singapore, and the Netherlands present pilot-based models of BIM–blockchain convergence, but these are grounded in high-capacity institutional environments characterized by strong enforcement, mandatory BIM standards, and mature digital ecosystems (see Table 1) [38,54,61,62]. Consequently, current theory-development is biased toward "technology-first" assumptions that do not reflect the realities of low-trust, weak-enforcement settings, where institutional constraints significantly limit technological impacts. This creates a theoretical blind spot: Can digital governance tools function effectively in contexts where institutional discipline is weak? The literature does not provide an answer.

Second, there is an absence of empirical research in Sub-Saharan Africa and Nigeria in particular. Nigerian scholarship on PPPs consistently highlights procurement opacity, documentation gaps, and enforcement weaknesses, but does not evaluate whether digital tools could meaningfully mitigate these failures [63,64]. Similarly, studies on BIM adoption in Nigeria focus on design-stage benefits and organisational barriers, without examining BIM as a governance mechanism [25,27]. Blockchain research in Nigeria remains largely conceptual and entirely disconnected from the construction or PPP sectors [25]. No published study has investigated BIM–blockchain integration as a transparency framework for PPP infrastructure governance in Nigeria or any comparable developing-country context.

Finally, the institutional conditions necessary for BIM–blockchain governance to succeed in weak regulatory environments remain theoretically unspecified. While scholars acknowledge the importance of institutional readiness, there is no empirical evidence identifying which legal, organisational, or cultural factors must be strengthened for digital accountability systems to function. This gap limits both theoretical development and policymaking.

Given these limitations, Lagos, responsible for nearly 30% of Nigeria's gross domestic product and home to many of the country's most high-profile PPP road projects, provides a uniquely relevant case for empirical investigation [14,60]. By examining stakeholder perspectives, institutional readiness, and the operational feasibility of BIM–blockchain integration, this study offers the first empirically grounded framework for understanding digital governance in Nigeria's PPP road sector, contributing to both national reform efforts and global debates on transparency in infrastructure delivery.

2.5. Research Gap and Study Rationale

Drawing together the theoretical and empirical limitations identified above, three interconnected research gaps emerge that this study addresses. First, there is no empirical evidence on how BIM–blockchain integration functions within weak institutional environments characterised by low enforcement capacity, fragmented documentation practices, and discretionary governance cultures. Existing studies assume institutional conditions that diverge fundamentally from those prevailing in developing economies such as Nigeria.

Second, while Principal–Agent Theory, Transparency Theory, and Institutional Theory collectively explain *why* PPP governance fails, the literature has not empirically examined whether or *how* digital tools could mitigate these failures in contexts where the institutional foundations for technology-enabled accountability are absent or underdeveloped.

Third, there is no theoretical framework specifying the institutional preconditions—legal, organisational, and cultural—that must be established before digital governance tools can deliver their intended transparency benefits. This study addresses these gaps by conducting the first empirical investigation of blockchain–BIM integration within Nigeria's PPP road sector, generating theoretical propositions about institution–technology alignment and practical recommendations for context-sensitive implementation.

3. Methodology

This study employed a qualitative research approach to investigate how Blockchain and Building Information Modelling could enhance transparency in Public–Private Partnership -funded road projects in Lagos, Nigeria.

3.1. Methodological Approach and Rationale for Qualitative Analysis

Before detailing the analytical procedures, it is important to address why this study employs qualitative thematic analysis rather than quantitative statistical evaluation. Three considerations justify this methodological choice.

First, the research questions are exploratory and theory-generating rather than hypothesis-testing: the study seeks to understand how blockchain–BIM integration might enhance transparency and what institutional conditions enable or constrain such integration, rather than measuring the magnitude of predetermined relationships. Quantitative approaches presuppose conceptual operationalisation and measurement validity that do not exist for an undertheorized phenomenon with no prior empirical research in comparable contexts [65,66].

Second, the phenomena under investigation—governance failures, discretionary practices, institutional resistance—are inherently context-dependent and require interpretive analysis of stakeholder experiences, meanings, and perceptions that cannot be captured through standardised measurement instruments.

Third, the absence of active blockchain–BIM implementations in Nigerian PPPs means there are no quantifiable outcomes, adoption rates, or performance metrics available for statistical analysis; the study necessarily relies on expert assessments and informed expectations rather than observable system performance. Nevertheless, the qualitative analysis maintains methodological rigour through systematic procedures including documented coding trails, saturation assessment, and reflexive engagement with the data, ensuring the credibility, transferability, and confirmability appropriate to interpretive research standards [67,68].

3.2. Conducting Interviews

Semi-structured interviews served as the primary data collection method, striking a balance between structure and flexibility through pre-drafted, open-ended questions that allowed for elaboration, clarification, and follow-up discussion [65]. This approach was considered particularly suitable for investigating institutional complexity and divergent stakeholder perceptions in Nigeria, where adaptability in questioning is essential. The interview guide was developed around thematic areas central to the study, transparency and accountability, information management, current BIM practices, blockchain potential, governance and legal frameworks, feasibility of pilot projects, and capability requirements, structured in alignment with ISO 19650 [30] principles of information management. Semi-structured interviews were chosen because they enable the capture of contextual nuances and decision-making processes often absent in secondary sources; for instance, while project reports document contractual variations, the underlying rationale is more meaningfully revealed through the lived experiences of practitioners [66].

A purposive sampling strategy was adopted to ensure alignment with the study's objectives. A total of ten experts from industry and academia were selected (see Table 2 for the details of the expert interviewees). This distribution provided a balanced representation and strengthened the credibility of the findings by incorporating perspectives from multiple stages of the PPP process. Participants were identified through Lagos State PPP Units and professional bodies such as the Nigerian Institute of Quantity Surveyors (NIQS) and the Council for the Regulation of Engineering in Nigeria (COREN), with eligibility restricted to practitioners involved in ongoing or completed PPP-funded road projects. Thematic saturation was reached after ten interviews, which is consistent with guidance for qualitative studies involving relatively homogenous expert groups. Because all participants were senior practitioners engaged in PPP-funded road projects and shared comparable professional backgrounds, roles, and exposure to sector-wide governance challenges, the dataset reflected a high degree of information repetition across interviews. In such homogenous expert samples, saturation is typically achieved with 8–12 participants [67], and by the tenth interview no new themes or divergent perspectives emerged, indicating sufficient depth and coverage for the study context. See Appendix A.3 for the detailed profile of survey respondents.

Table 2. Details of the interview respondents.

Respondent	Current Designation
E1	Procurement Officers
E2	Researcher
E3	Researcher
E4	Design Consultants
E5	Construction Managers
E6	Operations Managers
E7	Software Engineer
E8	BIM Researcher
E9	Software Engineer
E10	BIM manager

To minimise potential sampling bias, the purposive selection process intentionally included a diversity of viewpoints across the PPP lifecycle, including participants known to hold critical views on project governance and digital adoption. Respondents were drawn from both public- and private-sector organizations, as well as supervisory and operational roles, ensuring variation in levels of influence, digital maturity, and institutional affiliation. This heterogeneity reduced the likelihood of one-sided or overly favourable accounts and allowed the study to capture contrasting perspectives, including those critical of existing transparency mechanisms or sceptical about the feasibility of BIM–Blockchain integration. Moreover, participants were recruited through multiple independent channels (PPP units, professional bodies, and direct practitioner networks), which further reduced gatekeeper influence and enhanced the credibility of the sample.

3.3. Data Analysis

With participants' consent, all interviews were digitally audio-recorded, transcribed verbatim, and stored securely, thereby safeguarding ethical integrity and research transparency. A manual thematic analysis approach was undertaken to manage and interrogate the transcripts. This method enabled a close and iterative engagement with the data, en-

suring that the researcher remained reflexively immersed in both language and context. Thematic analysis, as outlined by Braun and Clarke [68], was adopted to identify, interpret, and analyse patterns across the dataset. This approach moved beyond descriptive reporting to allow a rich exploration of stakeholder experiences concerning transparency, governance, and digital integration.

Both deductive and inductive strategies were applied. While certain themes were sensitized by existing PPP governance literature (e.g., auditability, accountability frameworks), additional insights emerged inductively from participants' accounts. The coding process followed a systematic sequence beginning with repeated readings of the transcripts to achieve deep familiarization, followed by manual annotation of initial codes in the margins. These codes were progressively refined into broader categories through a process of axial coding, in which conceptual links were established (for example, between "contract variations" and "payment delays"). From these categories, higher-order themes were developed, including "transparency pain points," "BIM/CDE practices," "blockchain potential," "regulatory gaps," and "governance risks."

The manual process, documented through reflective memos and coding tables, ensured an auditable trail of analysis and enhanced the rigor and reliability of the study. Anchored in interpretivist orientation, the analysis emphasized not only the frequency of responses but also the contextual meanings embedded in stakeholder narratives, thereby enabling nuanced and in-depth interpretation of the findings.

3.4. Ethical Considerations

This study adhered to the ethical guidelines of Northumbria University and received approval from the institutional Research Ethics Committee. All participants were fully briefed on the purpose of the study, data-handling procedures, and their right to withdraw at any stage. Informed consent was obtained prior to each interview, and all data were anonymized using role-based codes (E1–E10) to protect participant identity. Digital recordings and transcripts were stored on encrypted, password-protected systems in line with General Data Protection Regulation (GDPR) and institutional data-management policies. Given the sensitivity of governance and transparency issues, interview questions were framed to focus on systemic challenges rather than personal misconduct, thereby minimizing potential risks to participants. A detailed account of the ethical procedures, including consent materials and data-management protocols, is provided in Appendix A.

4. Results

This section presents and analyses the findings from the expert interviews conducted for this study. The interviews provide practitioner-level insights into the transparency challenges affecting Public–Private Partnership Road projects in Lagos State and highlight how governance weaknesses manifest across the project lifecycle. By capturing the lived experiences of stakeholders, the results complement the literature review and offer context-specific evidence on procurement, design, construction, and operational phases.

4.1. Transparency Pain Points

The findings from the ten expert interviews reveal transparency as a central and recurring problem across the entire lifecycle of Nigerian PPP road projects. Respondents consistently emphasized that deficiencies in openness and accountability pervaded procurement, design, construction, and operations, with weaknesses in monitoring and enforcement allowing irregular practices to become normalized. These findings confirm earlier studies that have highlighted corruption, inadequate oversight, and limited institutional capacity as major impediments to PPP success in developing countries [2,28].

4.1.1. Procurement Phase: Pain Points, Mechanism Failures, and Digital Solutions

The procurement phase emerged as the most problematic stage in terms of transparency. Respondents described persistent manipulation in prequalification, biased bid evaluations, and inconsistent documentation. E1, E2, and E4 reported cases in which politically exposed or underqualified firms were shortlisted ahead of technically competent contractors. E1 noted that on the Lagos–Badagry Expressway, "*a company with little experience was shortlisted ahead of a more experienced contractor, leading to delays and cost overruns*." Likewise, E3 observed that "*a firm's missing papers went unnoticed while another was disqualified for the same reason*," highlighting inconsistent rule enforcement.

Although procurement is governed by established regulatory frameworks, these mechanisms frequently fail in practice [63,69]. Respondents explained that enforcement is weak, documentation remains paper-based, and bid decisions are often influenced by informal communication and political pressure. Disclosure portals are seldom updated, bid evaluation reports are inconsistently logged, and oversight bodies lack the independence and technical capacity required for rigorous compliance checks [43,69]. These weaknesses allow bid alterations, selective disclosure, and discretionary approvals to persist despite the existence of formal rules.

Digital solutions could address several of these vulnerabilities. Blockchain-based bid submission platforms would time-tamp all entries, preventing retroactive alterations or late insertions [25]. A BIM-enabled tender documentation environment could centralise design requirements and evaluation criteria, reducing discrepancies in submitted documents [60]. Together, Blockchain–BIM integration would create an auditable trail of procurement decisions and eliminate opportunities for manipulation.

4.1.2. Design Phase: Pain Points, Mechanism Failures, and Digital Solutions

Respondents identified similar transparency challenges during the design stage. Contractors often introduced design modifications without appropriate scrutiny or documentation. E3 explained that "*contractors sometimes adjust things to save money, but these changes are not always openly discussed*." These informal changes frequently bypass formal review procedures, creating inconsistencies that later affect construction quality and long-term performance.

Existing design oversight mechanisms, consultant reviews, design boards, and approval chains, are hindered by informal processes and fragmented record-keeping. Respondents noted that approvals are frequently communicated verbally or through unsecured digital messages, with no central record of changes. The absence of a Common Data Environment means multiple design versions circulate simultaneously, complicating accountability and masking unauthorised changes.

Digital solutions offer a more robust alternative. BIM can create a shared design environment with full version control, ensuring that all adjustments are logged and visible to stakeholders. Blockchain can further secure these records by generating immutable, timestamped entries for each design revision or approval. This combination would provide a transparent audit trail, reduce disputes, and ensure design integrity throughout the PPP lifecycle.

4.1.3. Construction Phase: Pain Points, Mechanism Failures, and Digital Solutions

Transparency failures also surfaced during the construction phase, particularly in progress reporting, inspection, and certification. E7 noted that "*certifications at times are performed without due checks*," indicating that some contractors obtain approvals without proper inspections. Respondents described fragmented communication channels, paper files, WhatsApp messages, and emails, which make it difficult to track who approved of

what, and when. Such fragmentation increases the risk of manipulation and obscures accountability.

Although construction oversight mechanisms, consultant site inspections, progress certificates, and monitoring dashboards, exist in principle, respondents reported that they are inconsistently applied. Manual approval processes lack traceability, while supervisors often face pressure to certify work prematurely. Record-keeping gaps further weaken the reliability of inspection reports, leaving room for unauthorized changes or inflated claims.

Digital solutions could provide a transparent, real-time alternative. BIM's 4D (time) and 5D (cost) functions can link construction activities with scheduling and budget data, enabling objective validation of progress. Blockchain-enabled smart contracts could automatically trigger milestone payments only when validated BIM updates are uploaded, ensuring that financial transactions reflect actual work completed. Together, these technologies would significantly reduce the scope for manipulated certifications and payment disputes.

4.1.4. Operations Phase: Pain Points, Mechanism Failures, and Digital Solutions

In the operations and maintenance phase, respondents highlighted discrepancies in toll revenue reporting, poor maintenance tracking, and inconsistent documentation of performance standards. E2 and E10 described mismatches between system-recorded toll collections and officially reported figures, while E9 noted maintenance certifications issued despite inadequate work. These issues reinforce persistent concerns about revenue leakages and weak accountability.

While toll collection systems, service-level agreements (SLAs), and periodic audits are intended to regulate operations, respondents indicated that these mechanisms are inadequately enforced. Manual reconciliation processes create opportunities for selective reporting, and audit teams lack real-time access to transaction data. Maintenance oversight remains heavily dependent on physical inspections, which are vulnerable to human error and corruption.

Digital solutions could strengthen operational transparency. Blockchain-based tolling records would create immutable transaction logs, enabling regulators to compare system-generated data with official reports in real time. BIM-based asset management models could support maintenance planning and verification, ensuring that maintenance claims correspond to actual conditions on site. The combined use of blockchain and BIM would therefore improve operational accuracy, prevent revenue manipulation, and reinforce long-term accountability.

Table 3 summarises the transparency pain points, mechanism failures, and proposed digital solutions across the PPP lifecycle.

Table 3. Transparency Pain Points, Mechanism Failures, and Proposed Digital Solutions Across the PPP Lifecycle.

PPP Phase	Key Transparency Pain Points	Failing Mechanisms	Proposed BIM/Blockchain Solutions	Primary Governance Objective
Procurement	• Manipulated prequalification and bid evaluation • Selective disclosure of tender information • Political influence on contractor selection	• Weak enforcement of procurement regulations • Paper-based and fragmented submissions • Limited independence of oversight bodies	• Timestamp bids using blockchain-based submission • Standardize tender information via BIM-enabled documentation • Record bid evaluation decisions in an immutable BIM–Blockchain audit trail	Integrity & Auditability

Table 3. *Cont.*

PPP Phase	Key Transparency Pain Points	Failing Mechanisms	Proposed BIM/Blockchain Solutions	Primary Governance Objective
Design	• Informal and undocumented design changes • Opaque approval processes • Conflicting design versions	• Fragmented communication channels • Absence of a Common Data Environment (CDE) • Reliance on verbal or unsecured approvals	• Centralize models in a BIM-based shared design environment • Secure approvals using blockchain-verified authorizations • Log revisions through immutable design change records	Traceability & Accountability
Construction	• Inadequate inspections and premature certifications • Manipulated progress reporting • Poor traceability of approvals	• Manual and discretionary certification practices • Dispersed records across paper and digital media • Weak enforcement of inspection protocols	• Validate progress using BIM 4D/5D integration • Automate milestone payments via blockchain smart contracts • Link verified work completion directly to payment authorization	Accountability & Enforcement
Operations & Maintenance	• Discrepancies in toll revenue reporting • Weak verification of maintenance activities • Selective performance disclosure	• Manual revenue reconciliation • Periodic audits without real-time visibility • Inspection-dependent maintenance oversight	• Record toll transactions on blockchain-ledgers • Track assets and maintenance through BIM-based lifecycle models • Compare real-time operational data with reported performance	Transparency & Monitoring

4.2. Blockchain and BIM Potential for PPP Road Projects

The interviews revealed strong recognition of the potential of Building Information Modelling and blockchain technologies to transform accountability in PPP road infrastructure projects. Although both tools are currently underutilized in Nigeria, participants highlighted their capacity to establish shared data environments, create immutable records, and enable automated controls. Collectively, these capabilities were viewed as mechanisms that could strengthen transparency, reduce inefficiencies, and enhance trust among stakeholders.

4.2.1. Utilising BIM for Transparency and Data Integration

BIM was identified as a powerful tool for centralizing project information across design, construction, procurement, and operations. By integrating data into a single source of truth, BIM has the potential to eliminate redundancies, reduce conflicts, and ensure the traceability of approvals [70].

Respondents, however, stressed that its application in Nigeria remains limited. E1, E4, E5 and E9 reported that BIM is primarily used for 3D modelling and clash detection, with little consistent application of 4D (time) and 5D (cost) functions. As E3 explained: "*We use BIM for 3D coordination, but the time and cost dimensions are rarely applied consistently*." Similarly, E1 underscored the missed opportunity for oversight: "*Approvals that are currently ad hoc could be tracked routinely in a BIM-enabled data environment*."

Respondents indicated that broader adoption of 4D and 5D BIM would require both targeted training and institutional incentives. Skill gaps were identified as a major barrier:

many engineers and evaluators lack the capacity to work with BIM scheduling tools, extract quantities automatically, or interpret 5D cost simulations. To address this, experts suggested structured capacity-building programmes focused on: (i) hands-on training in 4D sequencing and construction simulation; (ii) workshops on 5D cost integration, quantity take-off, and lifecycle cost modelling; and (iii) certification schemes led by professional bodies such as NIQS, COREN, and Nigeria Institute of Chartered Arbitrators (NIARB) to formally recognize BIM competency.

In addition to training, respondents emphasized the need for organizational incentives to encourage advanced BIM use. These include procurement requirements that reward contractors who submit BIM-integrated 4D/5D models, government mandates that standardize BIM deliverables across PPP road projects, and contractual provisions that tie payment milestones to verified BIM-based progress models. Such measures would create tangible motivations for firms to move beyond basic 3D modelling. When fully deployed, BIM provides real-time collaborative working, complete version control, and transparent audit trails [71]. This ensures that design changes, often contentious in PPP projects, are openly scrutinized and permanently logged. Global studies reinforce these insights. For example, research in other developing economies has shown that BIM adoption reduces design-related disputes, enhances contract management, and strengthens accountability [72]. Thus, BIM in Nigeria holds significant potential to evolve from its current restricted application into a comprehensive platform for accountability across the PPP lifecycle, provided institutional and cultural barriers are addressed.

4.2.2. Blockchain for Immutable Records and Smart Contracts

Blockchain was perceived by respondents as an important complement to BIM, particularly for its ability to provide immutable records of key project events, including bid submissions, design approvals, and maintenance certifications. E1, E7 and E8 emphasized that blockchain could prevent document manipulation and selective disclosure. E1 observed: *"With blockchain, there would be no backdating or hidden changes, everything would be traceable."* Likewise, E4 noted: *"Revenue records could not be altered once logged, which would address our biggest leakages."*

These perspectives align with the literature, which highlights blockchain's capacity to ensure traceability and immutability, thereby reducing recurrent PPP issues such as inconsistent records and politically influenced approvals [17,19]. A particularly promising application is the deployment of smart contracts, where milestone payments are automatically triggered once validated inspections are recorded on-chain. E6, E8 and E10 argued that this would directly address recurring disputes over certification and delayed payments, while also improving trust in toll revenue reporting. Evidence from international contexts further validates this potential. For instance, studies in the UK and Australia demonstrate that blockchain applications in infrastructure finance provide transparent, tamper-proof records of financial flows, thereby enhancing stakeholder confidence [39,73].

To illustrate these capabilities, several use cases emerged from the interviews. For example, during procurement, all bid submissions could be timestamped on a blockchain ledger, ensuring that no late submission is secretly inserted or earlier bids altered, an issue frequently cited by respondents. In the design stage, every change in pavement thickness or drainage layout could automatically generate a blockchain entry, creating a permanent audit trail that prevents undocumented modifications. During construction, a supervising engineer's site inspection, such as confirming that asphalt compaction meets standards—could trigger an automated smart-contract payment only after the corresponding BIM model update is verified. In the operations phase, toll booth transactions could be logged instantly on-chain, allowing PPP regulators to compare system-recorded revenue with

official reports in real time, thereby eliminating the revenue discrepancies highlighted by E2 and E10. These scenarios demonstrate how blockchain can move beyond conceptual promises to provide practical, phase-specific solutions that directly target the transparency failures identified across Lagos PPP Road projects.

4.2.3. BIM–Blockchain Integration

The integration of BIM and blockchain was regarded as a particularly transformative opportunity for PPP governance, combining the strengths of data integration with immutability and automation. E3 and E7 described how BIM events, such as a design shifting from "For Review" to "Approved for Construction", could automatically generate blockchain records, ensuring that approvals are permanently stored and beyond dispute. This integration, respondents noted, could enable real-time tracking, reduce conflicts, and foster stronger accountability throughout the project lifecycle.

Evidence from international pilot projects supports this optimism. Case studies in the UK and UAE indicate that blockchain-enabled BIM systems significantly reduce disputes and enhance trust among stakeholders [17,21]. Nonetheless, respondents were realistic about the challenges of adoption in Nigeria, stressing the need for enabling reforms. Specifically, they identified three key prerequisites: legal recognition of digital signatures and smart contracts; the establishment of national BIM standards; and structured training programmes to address critical skill deficiencies. Without such reforms, there is a risk that BIM–blockchain integration will remain theoretical rather than operational.

4.3. Barriers to the Adoption of BIM and Blockchain in Nigerian PPPs

Although BIM and blockchain were widely acknowledged by respondents as having significant potential to enhance transparency in Nigerian PPP road projects, their adoption is constrained by a range of barriers. These can be broadly grouped into three categories: institutional and policy barriers, skills and technical deficits, and organizational and cultural resistance.

4.3.1. Institutional and Policy Barriers

The absence of a robust policy framework and national BIM standards was the most frequently cited barrier. Respondents emphasized that BIM use in Nigeria is not mandated and therefore remains fragmented, inconsistent, and largely voluntary. As E3 explained: *"Without standards, BIM is applied in different ways across firms, so instead of being centralized, it becomes inconsistent."* Similarly, E2 noted that blockchain records cannot yet be legally enforced: *"On-chain approvals cannot be recognized because digital signatures and blockchain data are not accepted by Nigerian procurement law."*

The literature confirms that technological innovations in developing countries often face legitimacy challenges due to weak institutional backing [2]. Unlike the UK, which mandated BIM Level 2 standards for all centrally funded projects [39], Nigeria has not introduced equivalent requirements, slowing adoption and perpetuating fragmentation [6].

Respondents also drew attention to vested interests that hinder policy reform. Some officials were described as reluctant to adopt systems that would reduce their discretionary authority in procurement and approvals. As E9 remarked: *"Not everyone wants transparency, some people benefit from the current loopholes."* This observation reflects wider findings that governance cultures in weak institutional environments often perpetuate opacity and discretionary control [34,46].

4.3.2. Skills and Technical Deficits

A second major barrier relates to technical capacity and skills shortages. Respondents noted that site engineers and evaluators often lack the skills to operate BIM software

(Autodesk Revit 2025.4.4 version) effectively, while senior managers have little understanding of blockchain applications. As E7 explained: *"Most of our staff only use BIM for basic modelling, and blockchain is completely unfamiliar."* E4 further elaborates that these skill deficits are compounded by the high cost of software licenses and hardware, which makes BIM adoption particularly challenging for small- and medium-sized firms competing for PPP contracts.

These findings are consistent with literature indicating that BIM adoption in Africa is hindered by high software costs, limited training opportunities, and weak ICT infrastructure [74]. Blockchain adoption faces additional obstacles, including unreliable broadband connectivity along major road corridors, cybersecurity risks, and a shortage of local technical expertise [21]. Scholars argue that targeted capacity-building, alongside pilot projects supported by government and private partners, is essential to overcoming these barriers [11,75].

4.3.3. Organisational and Cultural Opposition

The third barrier relates to organisational culture and resistance to change. Respondents observed that older engineers and senior officials often prefer paper-based approvals, which they regard as more familiar and reliable. As E3 noted: *"Senior staff are comfortable with paper signatures. Digital systems are seen as disruptive."* Resistance was also associated with vested interests. E2 and E7 suggested that actors who benefit from the lack of transparency deliberately slow the adoption of digital technologies. E1 explained: *"People who profit from loopholes will resist blockchain and BIM, because these tools take away their discretion."* These findings mirror wider research showing that organizational culture constitutes a significant non-technical barrier to digital reform, particularly when transparency threatens entrenched practices [70]. Comparable patterns have been observed in other developing countries, where blockchain pilots have faltered when they disrupted informal but established practices [18]. In Nigeria, where a "flexible" approach to approvals is widely accepted, E4 and E9 cautioned that strict digital compliance may encounter strong cultural resistance unless its benefits are clearly demonstrated.

4.4. Emerging Mitigation Strategies

Although respondents identified multiple institutional, technical, and cultural barriers to the adoption of BIM and blockchain in Nigerian PPP road projects, they also proposed practical strategies that could enable gradual and sustainable implementation. These recommendations fall into three broad categories: policy and regulatory reforms, training and capacity building, and the use of technology sandboxes and incremental pilots.

4.4.1. Policy and Regulatory Reforms

There was clear consensus among interviewees on the need for legal recognition of digital records to legitimize the use of BIM and blockchain in PPP contracts. As E1 explained: *"Blockchain approvals cannot yet be used in procurement because the law does not recognize digital records."* Similarly, E2 emphasized the importance of establishing national BIM standards to ensure consistent use across projects: *"Without BIM standards, every submission is treated differently. We need rules to make it official."* E5 and E9 further suggested that the Bureau of Public Procurement (BPP) and state-level PPP units should take the lead by issuing national guidelines and mandating digital submissions for project documentation.

These perspectives align with international evidence. For example, successful BIM adoption in the UK and Singapore has been supported by strong regulatory frameworks and government mandates [39]. Similarly, blockchain pilots in India and Ghana demonstrate that state-driven legal reforms are critical to institutionalizing transparency technologies in infrastructure delivery [76,77].

4.4.2. Training and Capacity Building

A second major recommendation concerned systematic training and professional development. Respondents stressed that without targeted upskilling for managers, engineers, and evaluators, digital tools would remain underutilized. As E2 admitted: "BIM submissions are often ignored because evaluators don't know how to use the software." Furthermore, E4 added: *"Even top officials lack the confidence to interpret blockchain data, so they stick to paper."*

The literature strongly reinforces these findings, highlighting that digital transformation in the construction sector frequently fails when training is inadequate [78]. Recommended approaches include donor-funded capacity-building programmes, vendor-led blockchain workshops, and industry–academia partnerships to develop BIM and blockchain curricula [17]. International case studies also demonstrate that training not only improves technical proficiency but also reduces cultural resistance. In Malaysia and South Africa, training initiatives that explicitly demonstrated the benefits of digital adoption helped overcome entrenched reluctance to transparency [42,79].

4.4.3. Technology Sandboxes and Incremental Pilots

The third strategy proposed was incremental adoption through sandboxing and pilot projects. Respondents recommended starting with targeted, high-impact applications, such as tender submissions or toll revenue reporting, rather than attempting full-scale implementation from the outset. As E7 argued: *"We should test blockchain on small areas like toll reporting before applying it to the whole project."* Similarly, E3 emphasized the importance of building confidence gradually: *"Pilots create room to learn without risking large investments. If tendering or contract variations can be managed transparently on a small scale, then scaling up becomes much easier."* E5, further reinforced this approach: *"Incremental adoption allows regulators and contractors to align expectations. A controlled sandbox ensures compliance issues are identified early, before full rollout."*

This staged approach is consistent with international best practice, which emphasizes the role of sandboxing in high-risk sectors. Phased rollouts enable regulators and project participants to evaluate risks, refine processes, and build confidence before scaling up [55]. For example, blockchain procurement pilots in Chile and Estonia first enhanced trust and quality assurance at the pilot stage before being scaled to national platforms [2,55].

5. Discussion

This study explored how transparency in Nigerian PPP-funded road projects is undermined across the project lifecycle and examined the potential of Building Information Modelling (BIM) and Blockchain as complementary tools for improving accountability. Situating these findings within global literature reveals broad alignment with earlier research while also generating new theoretical insights. Central to this discussion is the argument that technology alone cannot resolve governance failures unless the institutional environment can support it. This study therefore adopts what it terms an institution-first pathway, which holds that digital tools deliver transparency gains only when robust legal, administrative, and enforcement structures already exist.

To illustrate this argument, Figure 1 compares two contrasting approaches to digital governance in PPPs: A technology-first pathway, where digital systems are deployed before institutional strengthening, and an institution-first pathway, where technology adoption follows the consolidation of rules, enforcement, and capacity. The findings strongly indicate that Nigeria currently follows the former, while sustainable digital governance would require a shift to the latter.

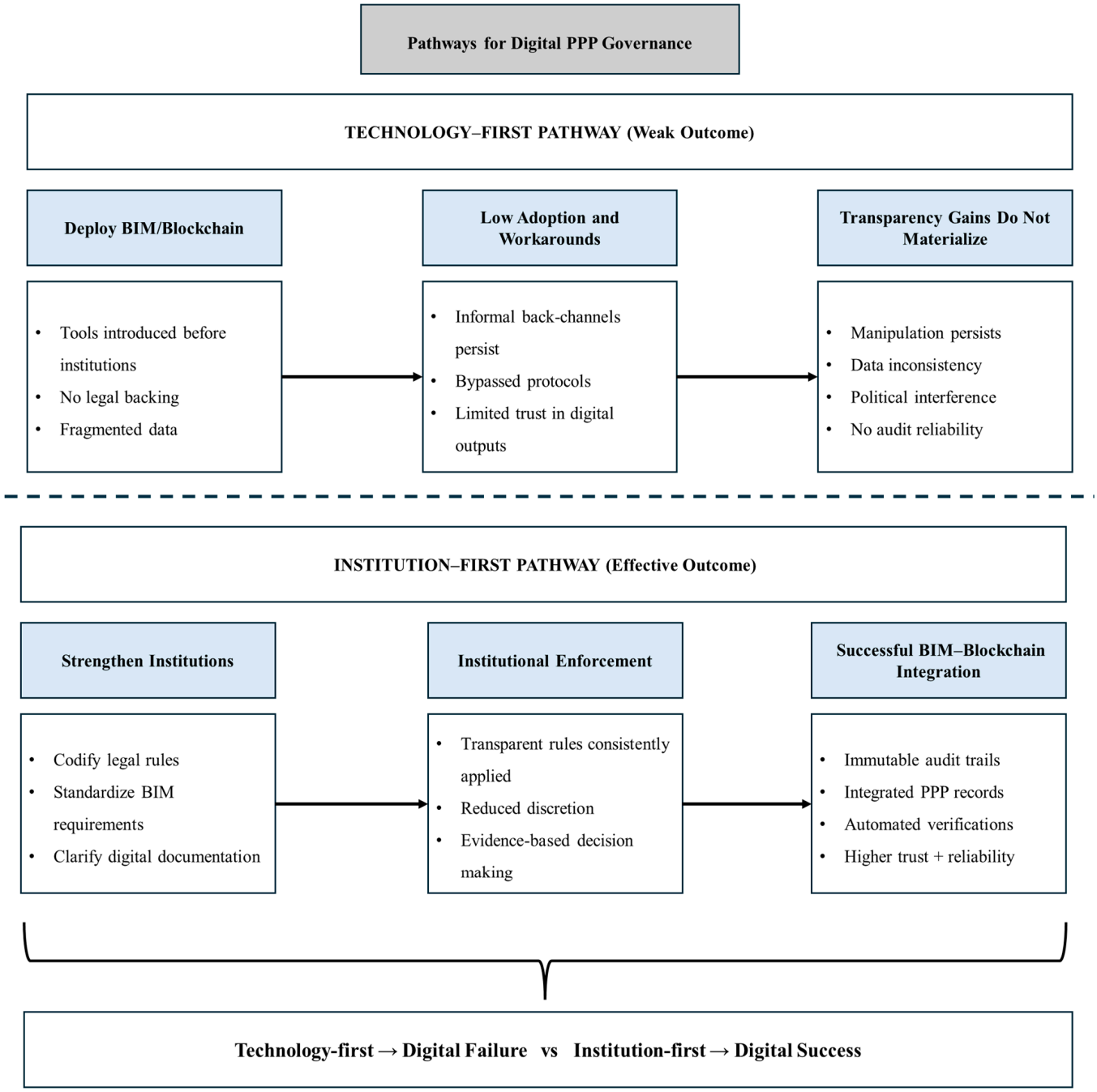


Figure 1. Comparison between the Technology-First and Institution-First pathways for digital governance in PPP road projects.

5.1. Persistent Transparency Deficits in Nigerian PPPs

Taken together, the findings indicate that transparency failures in Nigerian PPP road projects are systemic rather than phase-specific, reflecting entrenched institutional weaknesses rather than isolated operational lapses. The recurrence of similar governance breakdowns across the project lifecycle, summarised in Table 3, points to an institutional environment characterised by discretionary authority, weak enforcement, and informal decision-making practices. These findings confirm the assertions of Osei-Kyei [43] and Akpoghome [28], who emphasize that Nigerian PPPs are particularly vulnerable to corruption and weak oversight.

Globally, PPP literature recognizes that transparency deficits are not unique to Nigeria. For instance, the UK's National Audit Office [45] reported significant cost escalations in PPPs despite projects being delivered on time, while Brazil's PPPs were plagued by renegotiations within five years of contract signing [50]. Similarly, India's highway PPPs faced cost overruns due to governance bottlenecks [2]. However, the Nigerian case appears to amplify these risks, largely because of entrenched institutional weaknesses and informal project governance practices. Unlike advanced economies, where mandatory transparency frameworks, such as the UK's open procurement laws and Singapore's disclosure mandates, constrain discretionary manipulation [37], Nigeria's reliance on paper-based systems and informal communication (i.e., email, WhatsApp) provides fertile ground for opacity.

The findings therefore reinforce the arguments of Kouton et al. [80] and Shrestha et al. [34], who contend that the institutional environment, rather than contractual design alone, shapes PPP outcomes. In Nigeria, persistent opacity continues to erode public trust and investor confidence, indicating that the PPP model cannot achieve its intended socioeconomic benefits without substantial governance reforms.

5.2. Weak Enforcement of Accountability Mechanisms

Although Nigeria has established procurement and auditing frameworks, such as the Public Procurement Act (2007) [81] and Lagos State Procurement Law (2011) [82], this study shows that enforcement is weak and inconsistently applied. Respondents revealed that politically connected firms are prequalified despite limited technical capacity, certifications are issued without site inspection, and discrepancies in financial reporting go unchallenged.

These findings corroborate the work of Jacob and Umoh [16], who argue that Nigeria's challenge lies not in the absence of laws but in their ineffective enforcement. They also echo comparative research that emphasizes how PPP success in advanced economies stems from strong regulatory enforcement and independent oversight [10]. For example, in the UK, mandatory project disclosure ensures accountability [45], while in Singapore, independent monitoring units oversee PPP compliance [37]. In contrast, Nigeria lacks independent audit mechanisms and relies heavily on discretionary enforcement, widening opportunities for corruption and inefficiency.

This weak dynamic enforcement validates the claims of Hamledari and Fischer [19] that institutional strength is the most critical factor for PPP success. It also illustrates Trebilcock and Rosenstock [41] observation that policies in developing countries often adopt international standards on paper but fall short in practice due to inadequate enforcement capacity.

5.3. BIM as a Tool for Data Integration and Transparency

The study found that BIM is recognized by stakeholders as a powerful tool for centralizing project information, reducing redundancy, and ensuring traceability. However, in practice, adoption remains shallow, with usage restricted to basic 3D modelling and occasional clash detection. This mirrors earlier Nigerian studies [27] that highlighted fragmented and inconsistent BIM uptake. By contrast, global evidence illustrates BIM's transformative potential when systematically embedded into governance structures. In the UK, BIM Level 2 has been mandatory since 2016, improving accountability through standardized digital record-keeping [39]. Studies by Succar and Poerschke [18] and Boje et al. [17] demonstrate that BIM reduces disputes, improves contract management, and enhances auditability. The disparity between Nigerian practice and international experience reflects the absence of institutional support, regulatory mandates, and enforcement mechanisms.

Thus, this study reinforces the arguments of Ganah and John [39] and Succar and Poerschke [18] that BIM's governance potential remains unrealized in developing economies

due to high software costs, inadequate training, and the lack of national standards. The Nigerian case further illuminates that without government-backed policies, BIM adoption is likely to remain voluntary and piecemeal, aligning with Bello et al.'s [6] conclusion that digital tools cannot thrive in weak institutional environments. However, while the findings highlight BIM's value for transparency, they also point to an important caveat: overreliance on digital systems without complementary manual or redundant protocols may introduce new vulnerabilities. Experts noted that unreliable power supply, inconsistent internet access, and limited digital literacy in some agencies could disrupt BIM workflows. In such contexts, the absence of fallback documentation systems may inadvertently impede project oversight rather than strengthen it.

Therefore, effective BIM-enabled governance requires a hybrid approach in which digital systems are supported by minimum manual redundancies, clear data recovery procedures, and transitional protocols until full digital maturity is reached. This balanced model ensures that BIM enhances transparency without compromising operational resilience in environments where technological infrastructure remains uneven.

5.4. Navigating Technical Promise and Governance Barriers in Blockchain Implementation

Blockchain was widely perceived by respondents as a solution to document manipulation, selective disclosure, and revenue leakages. The technology's capacity to provide immutable records and automate milestone payments aligns with international evidence from the UK, Singapore, and the Netherlands, where blockchain-enabled smart contracts to have improved procurement transparency and reduced disputes [37,39].

However, unlike in these contexts, blockchain adoption in Nigeria remains almost nonexistent. This reflects both infrastructural limitations (unreliable internet, poor ICT systems) and institutional barriers (lack of legal recognition for digital records). The findings validate Hamledari and Fischer [19] and Leng et.al [51], who argue that blockchain adoption in construction depends not only on technical feasibility but also on institutional readiness.

Crucially, respondents highlighted vested interests as a barrier, with some officials deliberately resisting technologies that would reduce discretionary control. This resonates with Hamledari and Fischer [19], who emphasize that governance cultures often block reforms when transparency threatens entrenched rent-seeking practices.

5.5. Integration of BIM and Blockchain

The integration of BIM and blockchain was viewed as a potentially revolutionary approach to PPP governance in Nigeria. By linking BIM data events (e.g., design approvals, milestone completions) to blockchain records, stakeholders could achieve both data integration and immutability. This perspective mirrors findings from international pilots in the UK, UAE, and Singapore, where BIM–blockchain integration has reduced disputes and fostered trust [17,20,52].

Yet, this study contributes new insights by showing that the primary barriers in Nigeria are not technical but institutional and cultural. Respondents consistently pointed to the absence of national BIM standards, the lack of legal recognition for blockchain transactions, and cultural resistance to abandoning paper-based practices. These findings extend the literature by demonstrating that in developing contexts, integration is less about technology readiness and more about legal and institutional transformation.

5.6. Barriers and Mitigation Strategies

The study identified three principal categories of barriers to the adoption of BIM and blockchain in Nigerian PPP road projects: institutional and policy gaps, skills and technical deficits, and organizational and cultural resistance. At the institutional level, the absence of national BIM standards, the lack of legal recognition for blockchain records, and

policymakers' reluctance to constrain discretionary authority create structural weaknesses that undermine reform, echoing the World Bank's [2] argument that regulatory certainty is critical for digital transformation in infrastructure. Technical challenges further exacerbate these weaknesses: managers and engineers often lack digital literacy, while high software costs and inadequate ICT infrastructure hinder consistent uptake, mirroring constraints reported by Akpoghome and Nwano [28] and Calderon and Serven [3] across African construction sectors. Equally significant are organizational and cultural barriers, including entrenched preferences for paper-based approvals, generational resistance to adopting digital tools, and the persistence of vested interests that benefit from opaque systems. These findings strongly support Succar and Kassem [18], who emphasize that non-technical barriers frequently outweigh technical ones in shaping the success of digital transformation. To overcome these challenges, respondents recommended a suite of mitigation strategies, including incremental pilot projects, regulatory and policy reforms, and targeted capacity-building initiatives. These align with global best practices, such as the UK's phased BIM adoption [62] and blockchain sandboxing in Chile and Estonia [2]. However, a key contribution of this study is the insight that in Nigeria, beyond technical and procedural reforms, success will depend heavily on building political will to dismantle entrenched resistance and drive systemic adoption of digital governance tools.

5.7. Theoretical and Practical Contributions

Theoretically, this study advances digital governance scholarship by introducing the "Codify–Condition–Capacitate" framework, which provides a structured explanation of why transparency-enhancing technologies such as BIM and blockchain succeed in some PPP contexts and fail in others (see Figure 2). The framework demonstrates that digital tools produce governance benefits only when three institutional conditions align: (i) codified standards that legally recognize digital records and formalize data requirements, (ii) conditioned enforcement mechanisms that ensure consistent oversight and reduce discretionary decision-making, and (iii) capacitated actors and institutions with the skills, infrastructure, and incentives required for effective implementation. By empirically grounding this model in Nigeria's PPP road sector, the study contributes a context-sensitive theoretical pathway that challenges prevailing technology-first assumptions common in construction informatics literature.

Practically, the findings highlight the reforms required to operationalize this framework. Legal codification of digital processes, the establishment of national BIM standards, and formal recognition of blockchain-based records are foundational steps. Strengthening enforcement bodies and consolidating oversight processes will help condition the institutional environment for digital adoption. Finally, capacity-building programmes, targeted training, and incremental pilot implementations are essential to equip practitioners and reduce resistance to change. These insights form the basis of a roadmap for transforming Nigeria's PPP governance architecture.

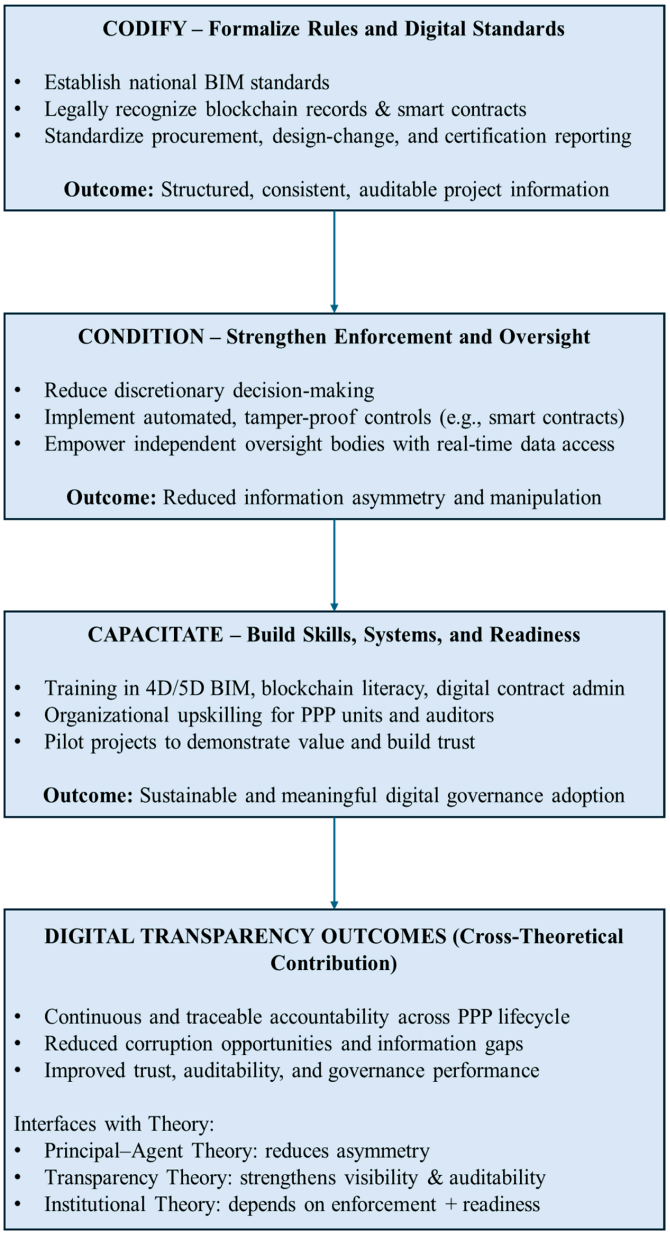


Figure 2. The Codify–Condition–Capacitate institutional pathway for digital governance in PPP projects.

5.8. Limitations and Future Research Directions

This study presents one of the first empirically grounded examinations of Blockchain–BIM integration for transparency in Nigerian PPP road projects, yet several limitations should be acknowledged. The absence of active Blockchain–BIM implementations in Nigeria also meant that the study could not observe real-time workflows or behavioral responses, relying instead on expert assessments and theoretical extrapolation. Furthermore, although the study draws on Principal–Agent, Transparency, and Institutional Theory to interpret governance challenges, the qualitative dataset did not allow for systematic testing of theoretical propositions or measurement of causal mechanisms. These constraints indicate that the findings should be interpreted as exploratory rather than predictive.

Building on these limitations, future research should extend this work through targeted pilot implementations, including blockchain-enabled tendering systems, BIM-linked design approval processes, or smart-contract-based milestone payment mechanisms. Such pilots would generate crucial empirical evidence on operational feasibility, efficiency gains, and stakeholder acceptance under real project conditions. Given that BIM–Blockchain

integration has not yet been operationally deployed in Nigeria, the evidence presented in this study reflects informed expert expectations rather than observed performance impacts.

Comparative studies across multiple Nigerian states, or between countries with varying levels of institutional maturity, would further illuminate the threshold conditions (legal reforms, capacity levels, ICT infrastructure) required for successful adoption of Blockchain–BIM governance tools. In addition, longitudinal research is needed to evaluate whether digital transparency mechanisms lead to lasting institutional improvements or whether benefits diminish due to cultural resistance or risks of "dashboard formalism". Such work would deepen theoretical understanding and refine the Codify–Condition–Capacitate framework proposed in this study.

6. Conclusions

This study examined the transparency challenges undermining Public–Private Partnership (PPP) road projects in Lagos State and evaluated the potential of Building Information Modelling (BIM) and Blockchain as complementary governance tools. The findings reveal persistent opacity across the PPP lifecycle, including biased bidder selection, undocumented design changes, manipulated certifications, and toll-revenue discrepancies, driven less by legislative gaps than by weak institutional enforcement. These insights extend Principal–Agent, Transparency, and Institutional Theory by showing that digital technologies cannot reduce information asymmetry or strengthen accountability unless embedded within robust institutional frameworks.

BIM and blockchain offer significant yet conditional benefits. BIM enhances traceability and collaborative oversight through centralized, version-controlled data environments, while blockchain provides immutable audit trails and smart-contract automation to limit discretionary manipulation. However, their effectiveness in Nigeria is hindered by the absence of national BIM standards, limited digital skills, infrastructural constraints, and cultural resistance to administrative reform. These conditions underscore the need for an institution-first pathway, where governance discipline precedes technological enforcement.

To operationalize this pathway, the study proposes a three-pillar reform agenda: codifying digital policies and standards; conditioning enforcement mechanisms to reduce discretionary authority; and capacitating institutions and practitioners through targeted training and phased pilot projects. This sequencing minimizes risks such as administrative overload or superficial "dashboard formalism," ensuring that digitalization enhances rather than weakens governance.

This study makes three distinct original contributions to knowledge. First, it provides the first empirical investigation of BIM–blockchain integration for PPP governance in a developing-country context, addressing a significant gap in scholarship that has been predominantly confined to high-capacity institutional environments. Second, the study advances an original theoretical framework—the Codify–Condition–Capacitate model—that explains the institutional preconditions under which digital governance tools can improve transparency, challenging the technology-first assumptions prevalent in construction informatics literature. Third, the study generates significant practical implications by identifying context-specific implementation strategies that can inform policy reform in Nigeria and comparable developing economies. Methodological rigour was ensured through systematic procedures including purposive sampling, saturation assessment, documented coding trails, and iterative analytical refinement, thereby establishing credibility, transferability, and confirmability appropriate to qualitative research standards.

Overall, the study provides both a conceptual contribution and actionable guidance for Nigeria and other developing contexts seeking to strengthen PPP transparency through responsible, institution-aligned digital transformation.

Author Contributions: Conceptualization, K.A.E. and A.P.R.; methodology, K.A.E. and A.P.R.; validation, K.A.E. and A.D.R.; formal analysis, A.D.R. and A.P.R.; investigation, A.D.R. and A.P.R.; writing—original draft preparation, A.D.R. and A.P.R.; writing—review and editing, A.P.R., A.D.R. and B.G.; visualization, A.D.R.; supervision, A.P.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This project was ethically approved by, Ethic Committee Name: Ethics Steering Committee- School of Architecture and Built Environment, Northumbria University, Approval Date: 25 June 2025.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Appendix A.1. Interview Guideline

Study Title: Enhancing Transparency in PPP Road Projects in Nigeria: Expert Perspectives on BIM–Blockchain Integration

Purpose of Guide:

This guide for semi-structured interviews aims to elicit answers from PPP-funded road project stakeholders in Lagos State on issues of transparency, use of digital technology, and whether Blockchain integration is feasible in the future. These questions are aligned to PPP transparency, ISO 19650- [30] style information management, and realistic BIM-Blockchain integration points.

A. Role & Context (warm-up)

1. Role & involvement: Briefly describe your role and the PPP road project stages you cover. (Procurement/design/construction/operations/maintenance).

B. Transparency & Accountability Today

2. Breakdowns: Where do transparency gaps most often occur (e.g., prequalification, bid evaluation, contract variations, certification/payments, toll/revenue reporting)? Please give one concrete example.

Probes: Which documents were involved? Who approved of what? What evidence exists?

3. Controls: What formal mechanisms currently ensure accountability (disclosure rules, audits, dashboards, performance reports)? How effective are they, and why?

C. Information Management (BIM/CDE/"ISO-style" concepts)

4. Data flows: What information is created and approved at each stage, by whom, and where is it stored/shared (CDE DMs, email, paper)?

Probes: Naming/versioning conventions; access rights; status/approval codes; who is the "appointing party" for information.

5. Pain points: Where do handovers, approvals, or record-keeping fail to become opaque?

D. BIM Use in Practice

6. Current uses: Which BIM uses are implemented (4D progress, 5D cost, quantity take-off, as-builts/asset register)?

Probes: BIM Execution Plan (BEP) contents; model approval workflow; dependencies on schedules/Define as Bills of Quantities (BoQs).

7. Barriers: What hinders wider BIM use (skills, contracts, standards, hardware, policy)?

E. Blockchain Opportunities

8. High-value targets: Which processes would benefit from tamper-proof logs or smart-contract triggers (progress certification, milestone payments, change orders, material provenance, inspection sign-offs), and why?

9. Trigger data: What BIM/field data or events could realistically trigger those processes (model status, 4D schedule events, site inspections, IoT readings)?

Probes: What validations and sign-offs are required? Who attests data quality? Minimal data needed?

F. Governance, Legal, and Risk

10. Constraints: What legal/policy issues matter (data ownership, admissibility of digital records, smart-contract enforceability, cybersecurity, privacy)?

11. Risks &mitigations: Key risks or unintended consequences (vendor lock-in, skills gaps, resistance, cyber threats) and practical mitigations (training, sandboxing, stage rollouts, independent audits).

G. Pilot & Outcomes

12. Pilot choice: If we piloted BIM-Blockchain on one process, which would you prioritise and why?

13. KPIs: What success measures would convince you it works (e.g., days from certificate to payment; percentage of disclosures published on time; dispute-cycle time; data/model completeness; audit findings)?

H. Capability & Adoption

14. Readiness: What capability, contract, or policy changes would make adoption feasible in your oranisation within 12–24 months?

Closing

15. Anything else: Is there anything that we have not covered that is important for improving transparency in PPP road projects?

16. Follow-up: May I contact you for clarification or to request artefacts (e.g., forms, model views, logs)?

Appendix A.2. Project Ethics Approval Form

You should use this document if you intend to use one of the existing module level approval ethics applications. Please complete this document and discuss your study with your supervisor before you collect any data.

Failure to complete this document and have all aspects signed off and approved by your supervisor risks a notable deduction in your grade and may risk a case of Academic misconduct. Please see the module handbook for more details.

Please ensure that your project meets the conditions of the existing ethics application (available on Blackboard). If it does not, then you will need to submit a full ethics application instead.

Table A1. Completed Project Ethics Approval Form for the Study on BIM and Block-chain Integration in PPP Road Projects.

Student Name:	
Project Title:	Exploring the Integration of BIM and Blockchain to Improve Transparency in PPP-Funded Road Construction Projects in Lagos State, Nigeria
Supervisor Name:	
Ethics application you are amending (check box):	☐ Questionnaire Study * √ Interview Study * ☐ Low Risk Secondary Data Study *

* No personal or confidential data (participants or business sensitive data), No experimentation on human, animals, human tissues, etc.

Introduction to the project: Please provide aims and objective of your project. This should provide the context of your research and clearly state hypothesis. Make reference to appropriate studies (500 words maximum).

Treat like an introduction to the study. Why is your proposed study important? What has already been done on the topic? How does your proposed study 'fit' with the current literature and what does it add? What is the aim of the proposed study? Make reference to appropriate studies.

Table A2. Completed Project Ethics Approval Form for the Study on BIM and Block-chain Integration in PPP Road Projects.

This study aims to explore the feasibility and stakeholder expectations of integrating Building Information Modelling (BIM) and Blockchain technology to improve transparency in PPP-funded road construction projects in Lagos, Nigeria. Despite the growing adoption of BIM globally, and the emerging interest in Blockchain for construction transparency [33], the synergy of these two technologies remains underexplored in the African context. Transparency is a persistent challenge in Nigeria's PPP infrastructure sector, where governance, accountability, and timely project delivery are often compromised [12,16]. BIM offers a collaborative digital platform for centralised project information, while Blockchain provides immutable, verifiable transaction records. When integrated, these tools could create a secure, transparent system for documenting construction progress, triggering smart contracts for approvals and payments. The research builds on previous literature examining BIM adoption in developing countries [6,22] and Blockchain applications in the built environment [19,20], with the aim of contributing a contextualized conceptual framework for Nigeria's PPP road sector. Aim: To evaluate the practical feasibility and stakeholder perceptions of integrating BIM and Blockchain to enhance transparency in PPP-funded road construction projects in Lagos, Nigeria. Objectives: 1. Assess current PPP transparency practices in Lagos road projects. 2. Examine stakeholder perceptions of BIM and Blockchain adoption. 3. Identify barriers to integrating the two technologies. 4. Propose a conceptual model for BIM-Blockchain integration in Nigeria's PPP infrastructure sector.

Methodology: Please provide the description of research activities such as design, methodology, and analysis.

Please complete the table below, using the following info to guide you. Write this as a future tense method. Describe the participants that you will recruit, how many you are going to recruit, and indicate if you have any additional exclusion criteria. Include the research design (e.g., randomised/repeated measures/quantitative/qualitative/case study etc) and detail of your proposed procedures (i.e., how are you collecting the data?). Include information on all of the equipment you plan to use. If this is a low-risk study, outline how you will extract data and list the criteria you will use to do this. Somebody should be able to read this and replicate it. Describe all planned data analysis for both quantitative (e.g., *t*-tests, ANOVA, correlation etc.) and qualitative (content analysis, thematic analysis etc.) data. If doing a low-risk study explain how you intend to analyse the data you have collected. Use literature to justify your method.

Table A3. Proposed Methodology and Ethical Considerations.

1.	Is this a low-risk secondary data study? If Yes please go to questions 6 and 7.	☐ YES √ NO
2.	Who are your participants and what is the inclusion criteria?	Participants will be professionals involved in Lagos State's road infrastructure delivery and regulation, including: • Engineers • Project managers • PPP unit officials • BIM coordinators • ICT consultants Inclusion Criteria: • Minimum of 3 years' professional experience in infrastructure or PPP projects in Nigeria. • Direct involvement in road construction or governance roles.
3.	How many will you recruit and from where?	8–10 participants recruited through professional networks, Linkedin outreach, and referrals from existing contacts in Nigeria's construction and PPP sectors.
4.	Are there any exclusion criteria (reasons why people should not participate)?	Exclusion criteria: • Individuals without professional experience in PPP road projects. • Individuals unwilling to provide informed consent.
5.	Research design:	Research design: Exploratory qualitative study using a single embedded case study (Lagos-Badagry Expresswaay) and semi-structured interviews.
6.	Procedures (describe what you will do to collect data, include all equipment/methods you plan to use).	Procedures: • Develop open-ended interview questions based on literature review. • Pilot-test the questions with 1–2 professionals before main data collection. • Conduct interviews asynchronously via a Google Form due to geographic and scheduling constraints. • Participants will first receive a digital information sheet and consent form. • Interviews will be conducted remotely to eliminate physical risk.
7.	Data analysis methods:	Data analysis methods: Thematic analysis will be conducted manually to identify recurring patterns and themes within the data. An inductive coding approach will be applied, in line with qualitative research best practices [68].
8.	Additional information:	No physical risk—all interviews conducted remotely.

Physical Risk Involved: All KA7068 projects involved physical risk. Please complete the risk assessment form and get necessary approval.

No physical risk. All interviews conducted remotely.

Risk assessment form completed:

Risk assessment form completed?

✔ Yes ☐ No

Data Management: Describe any arrangements for anonymising data and if not appropriate explain why this is and how it is covered in the informed consent obtained.

Data Management

Data will be stored in encrypted University OneDrive (or equivalent secure cloud), with access restricted to the researcher and supervisor. Data will be retained for 12 months post-assessment and then permanently deleted.

Anonymisation will be achieved through pseudonyms and removal of direct identifiers. All participation is voluntary; questions are non-sensitive; participants may skip any question or withdraw at any time.

Describe the arrangement for the secure transport and storage of data collected and used during this study. You should explain what kind of storage you intend to use e.g., cloud based storage, portable hard drive, USB stick etc.

Standard phrases have been added to the ethics application. In rare instances, these may not be appropriate for your study. If not please describe below.

Please check this box after you have read and understood research ethics and health and safety information.

✔ ☒ I confirm I have read the University's health and safety policy and Research ethics policy. I have read and understood the requirement for the mandatory completion of risk assessments and that my study does not deviate from the module level approval ethics forms on Blackboard.

https://www.flipsnack.com/northumbriaod/h-s-policy/full-view.html (accessed on 10 August 2025)

https://www.northumbria.ac.uk/media/27327041/nu-research-ethics-governance-handbook-2016-17.pdf (accessed on 10 August 2025)

https://www.northumbria.ac.uk/research/research-data-management/ (accessed on 10 August 2025)

Supervisor Statement

☒ I confirm that I reviewed the content of this form and agreed with the information provided.

Appendix A.3. Detailed Profile of Survey Respondents

Table A4. Detailed profile of survey respondents.

Criteria												
Professional experience and knowledge understanding Compulsory qualifications							Additional qualifications Satisfy at least one					
	Satisfy at least two						Satisfy at least one					
Coding for Panel Experts	Current Designation	1	2	3	4	5	6	7	8	9	10	Accessibility
E1	Procurement Officers	✔	✔				✔	✔	✔	✔		✔
E2	Researcher	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔
E3	Researcher	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
E4	Design Consultants	✔	✔		✔	✔	✔	✔	✔	✔		✔
E5	Construction Managers	✔	✔	✔		✔	✔	✔	✔	✔		✔
E6	Operations Managers	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔
E7	Software Engineer	✔	✔				✔	✔	✔	✔		✔
E8	BIM Researcher	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
E9	Software Engineer	✔	✔	✔			✔	✔	✔	✔		✔
E10	BIM manager	✔	✔	✔		✔	✔	✔	✔	✔		✔

1. Road construction practice (at least 5 years)
2. Involved in PPP projects
3. Building Information Modelling practice (at least 5 years)
4. Blockchain practice (at least 5 years)
5. Procurement Management (at least 5 years)
6. At least 10 Years of working experience in the Construction Industry
7. Having a construction-related bachelor's degree
8. Having a construction-related postgraduate degree
9. Having a built environment related to professional qualifications
10. At least 5 Years of experience as a Researcher in a related area

✔ indicates that the expert satisfies the corresponding qualification or criterion listed in the table.

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