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Integrating Blockchain and BIM for Transparent Heritage Restoration to Mitigate the Challenges of Authenticity and Integrity: A Theoretical Framework

Yasin Celik[1*], Tuğçe Büşra Su-Cadirci[2]

[1]Department of Architecture, Faculty of Art and Design, Artvin Çoruh University, 08000 Artvin, Türkiye (celiky@artvin.edu.tr)
[2] Department of Architecture, Abdullah Gul University, 38080, Kayseri, Turkey (tugcebusra.su@agu.edu.tr)
[*]Corresponding author

Abstract – Heritage restoration projects face numerous challenges, including the preservation of historical accuracy, effective stakeholder collaboration, and maintaining transparent records of interventions. This paper proposes a theoretical framework that integrates Building Information Modelling (BIM) with blockchain technology to overcome these challenges and preserve the authenticity and integrity of heritage restoration. The integration of BIM's digital modeling capabilities with blockchain's decentralized immutable ledger creates a transparent, traceable system for managing heritage restoration projects. The proposed framework enhances trust among stakeholders, streamlines regulatory approvals, and ensures the long-term preservation of both the digital and physical aspects of heritage assets. Although this integration holds significant potential, the study also highlights key challenges such as cost implications, and ethical considerations. Future work is needed to develop practical implementations, define standards, and address legal and policy gaps to facilitate the adoption of this innovative approach in heritage conservation.

Keywords – Heritage Restoration, Building Information Modeling (BIM), Blockchain, Digital Preservation, Stakeholder Transparency

I. Introduction

Historic buildings and cultural heritage sites are a specific connection to the past, representing the values, traditions, and architectural achievements of previous generations [1]. The restoration and preservation of such structures require technical precision [2], accountability [3], transparency [4], and coordinated collaboration among various stakeholders [5]. However, heritage restoration projects often suffer from fragmented workflows [6], lack of traceability [7] and inadequate documentation, which can compromise both the authenticity and integrity of the process [8].

Different cultural heritages are encompassed by place and time, each deserving respect for the values, traditions and perspectives of others [9]. Authenticity and integrity are therefore linked to landscape, a fundamental element of cultural heritage that integrates both built structures and the natural environment [10]. A significant landscape reflects the identity of its local culture and recognizes the presence and perspectives of contemporary users, including local communities and tourists. The activities and functions that take place in these areas contribute to their cultural significance and are important in building the social fabric that defines them [10].

Standardized solutions are often inadequate to address the unique environments of heritage sites. Each site has its own character and contextual sensitivity, its relationship to other cultures, its historical layers across time and space, and these need to be carefully preserved for future generations. The challenges facing authenticity and integrity in the urban environment are illustrated in Figure 1. To preserve authenticity and integrity, strategic planning, regular inspection, maintenance and conservation of the historic environment should be implemented to address the challenges to authenticity and integrity as key responsibilities of heritage authorities [10].

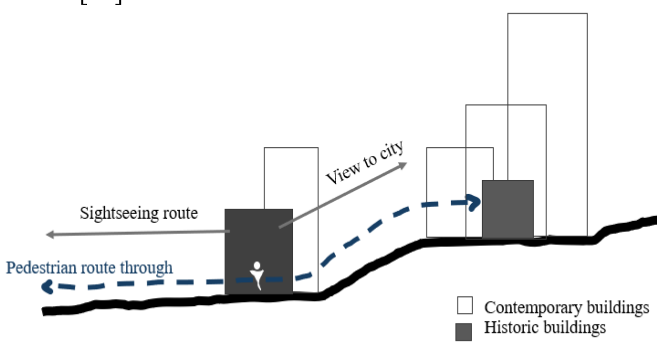

Figure 1. The dynamics of historic buildings challenges authenticity and integrity in urban context

Emerging digital technologies offer promising solutions to these challenges. Building information modelling (BIM) has become a fundamental tool in the architecture, engineering and construction (AEC) industry, enabling the creation of detailed digital representations of physical structures throughout their lifecycle [11]. Meanwhile, blockchain technology - known for its decentralized, tamper-proof ledger - has gained attention for its potential to increase trust, transparency and traceability in complex data ecosystems [12].

Blockchain technology, as an emerging tool in the sector, can provide a framework for these interventions to be recorded over time by decentralized authorities and linked to specific locations and conditions. Providing trust, transparency and traceability in complex data ecosystems, blockchain is particularly valuable in heritage management [13]. It can also facilitate a more coherent relationship between contemporary developments and historic environments by tracking the socioeconomic dynamics of new facilities. This traceability helps to reduce the difficulties associated with integrating contemporary buildings into historic urban environments or with the relationship of historic buildings to contemporary urban environments [14]. This paper proposes a conceptual framework for the integration of BIM and blockchain technologies in the heritage restoration. The aim is to present a theoretical model that explores how these technologies can be aligned to support transparent documentation, secure information exchange and reliable decision-making processes.

By reviewing existing literature and identifying key intersections between BIM and blockchain, this study highlights the potential of their integration to improve collaboration, reduce information loss, and increase accountability in restoration practices. The framework presented serves as a basis for future empirical research and practical applications in digital heritage conservation.

II. Literature Review

The integration of digital technologies into the AEC workflows has been transformative, particularly in the domains of building documentation, project coordination, and information management [15]. In heritage conservation, however, these technologies present both opportunities and challenges due to the historical, legal, and cultural sensitivities [16].

BIM is widely recognised for its ability to centralise project data in a 3D parametric environment, improving collaboration and decision-making [17]. In the heritage conservation, Historic Building Information Modelling (HBIM) has emerged as a specialised extension of BIM, designed to address the irregular geometries, diverse materials, and documentation gaps commonly found in heritage structures [18].

Studies have shown that HBIM can support restoration planning by integrating geometric data from laser scanning or photogrammetry with historical records and material properties [19]. However, challenges remain, including a lack of standardised protocols for modelling historical elements, limited interoperability between software platforms, and concerns about long-term data preservation [20].

Blockchain has become increasingly relevant in sectors that require secure, immutable record-keeping. In construction and asset management, blockchain has been explored for contract management, supply chain tracking and as-built documentation. Its decentralised architecture and cryptographic validation make it suitable for environments with multiple stakeholders and potential trust deficits [30].

The integration of BIM and blockchain presents practical solutions to the main risks in heritage restoration as summarised in Table 1.

Tablo 1: Key Challenges and Theoretical Mitigations

Challenge in Heritage Restoration	**Theoretical Risk**	**Mitigation via BIM + Blockchain Integration**
Loss of authenticity [21]	Untracked changes may alter original design [21]	BIM records details; blockchain stores them securely
Data manipulation or undocumented changes [22]	Loss of trust in project records, affect integrity [23]	Blockchain records all actions; BIM also tracks updates
Lack of coordination among stakeholders [24]	Miscommunication, delays [25]	Smart contracts automate approval workflows
Documentation inconsistency [16]	Conflicting information over time [26]	BIM provides a centralized data model; blockchain ensures traceability
Legal and regulatory complexity [27]	Unclear or delayed compliance checks [25]	Transparent, timestamped logs aid verification and auditing
Long-term archiving of restoration records [28]	Digital files may be lost or outdated [29]	Blockchain guarantees persistent, verifiable record storage

Although still in its early stages, the application of blockchain in built heritage has been proposed to support transparent decision-making and data integrity in conservation projects. For example, blockchain can record and timestamp every change made to a BIM model, creating a verifiable history of interventions [31]. However, questions remain regarding scalability, data privacy, and the integration of blockchain with existing BIM platforms [32].

While BIM and blockchain individually have been the subject of increasing research in the AEC domain, studies combining the two technologies-particularly in the cultural heritage domain-remain limited. Preliminary conceptual work suggests that blockchain can complement BIM by ensuring data transparency and secure version control. However, a comprehensive framework for its integration in cultural heritage restoration processes is lacking [31].

Most of the existing literature focuses on technical feasibility or theoretical benefits, often without considering the specific constraints of heritage contexts, such as legal oversight, authenticity verification, or community engagement. There is a need for a structured approach that articulates how BIM and blockchain can collectively address the diverse requirements of heritage conservation.

III. Conceptual Framework

This section outlines a theoretical model for integrating BIM and blockchain technologies in the heritage restoration. The proposed framework aims to address key issues in restoration projects such as lack of data traceability, poor documentation practices, and limited stakeholder accountability.

The proposed integration aims to achieve the following objectives:

- Ensure data integrity across all phases of restoration through immutable records.
- Facilitate transparent collaboration between architects, engineers, conservators, government bodies, and contractors.
- Enable traceable decision-making and intervention history, especially in compliance with cultural heritage regulations.
- Preserve digital heritage records for long-term archiving and future reference preserving the authenticity and integrity of heritage restoration.

The conceptual model consists of three primary layers, seen in Table 2.

Tablo 2: Conceptual Framework for Integrating BIM and Blockchain in Heritage Restoration

Layer	Component	Function	Stakeholders Involved
1. BIM Layer	Historic Building Information Model (HBIM)	Central digital model of the heritage structure, integrating geometry, materials, and historical data	Architects, Surveyors, Historians
	Intervention Records	3D representations and documentation of proposed and executed restoration activities	Conservation Experts, Engineers
	Metadata Integration	Embedding historical references, inspection reports, and archival documents	Cultural Institutions, Archivists
2. Blockchain Layer	Immutable Ledger	Permanent, timestamped log of all actions, updates, and decisions in the restoration lifecycle	All project stakeholders
	Cryptographi c Hashing	Verification of BIM model changes without storing full model data on-chain	Blockchain System Administrator s
	Smart Contracts	Automate approvals and enforce stakeholder agreements for restoration actions	Legal Advisors, Project Managers
3. Access & Governance Layer	Role-Based Permissions	Assign and control access rights to BIM elements and blockchain actions	Project Managers, Government Agencies
	Multi-Signature Validation	Require consensus from designated parties before implementing critical interventions	Heritage Boards, Restoration Authorities
	Change History & Version Control	Maintain a verifiable record of model revisions and approvals throughout the project	Auditors, Future Restorers

a) *BIM Layer: Digital Representation of Heritage Assets*
This layer includes the creation and ongoing management of a parametric HBIM model that integrates:

- Geometric data (e.g., from laser scans)
- Material specifications
- Historical records
- Planned interventions

This serves as a central, structured digital repository representing both the physical state and historical context of the heritage asset. However, it emphasises of the need for an open access library.

b) Blockchain Layer: Trust and Data Authentication
Blockchain acts as a validation and tracking mechanism for all interactions with the BIM model. Each modification (e.g., proposed restoration, material change, funding approval) is:

- Timestamped
- Linked to a unique identity (stakeholder account)
- Stored as a cryptographic hash on a permissioned blockchain

This ensures an immutable audit trail of all actions performed throughout the project lifecycle.

c) Access & Governance Layer: Stakeholder Permissions and Workflow

Different stakeholders (e.g., restoration experts, architects, municipal authorities, heritage boards) are assigned roles within a permissioned blockchain system, enabling:

- Role-based access to BIM elements
- Multi-signature approvals for critical changes
- Version control and rollback history

The governance model enforces transparency and accountability in decision-making while allowing collaboration without compromising sensitive or restricted data.

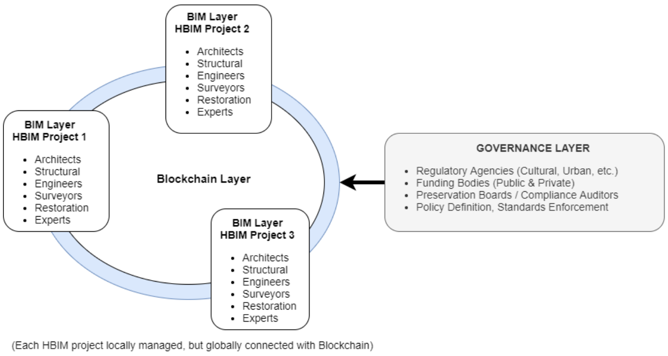

Figure 2. The diagram for conceptual model

The multi-project heritage restoration systems across three layers as seen in Figure 2. The governance layer provides oversight through project managers, government agencies, and heritage boards, ensuring compliance with preservation standards via role-based permissions and multi-signature validation. The blockchain layer serves as a decentralized infrastructure, using an immutable ledger to log all actions, updates, and decisions across projects, with cryptographic hashing verifying BIM model changes and smart contracts automating approvals. The BIM layer manages individual project execution, where teams of architects, historians, surveyors, and conservation experts develop HBIM. These models integrate geometry, materials, and historical data while documenting restoration activities. Blockchain connects all projects for synchronization, ensuring transparency and verification across the entire portfolio. This integrated approach ensures efficient, transparent management, while maintaining high data integrity across multiple heritage restoration projects.

Process flow overview of the framework presented in Table 3:

Tablo 3: Flowchart of the Heritage Restoration Process with BIM and Blockchain Integration

Action	Tools	Stakeholde rs	Blockchain Role	BIM Role
Project Initiation	Initial data collection	- Architects - Historians	Blockchain records the start of the project, timestamping all initial data	BIM models are created with geometric data
BIM Model Creation	BIM software	- Architects - Surveyors	Blockchain logs metadata and provenance validation records	3D BIM model is developed to represent the structure and context
Proposed Interventi ons	BIM software	- Engineers	Blockchain records each proposed	BIM model is updated with proposed

		- Conservators	intervention (timestamped, signed by relevant parties)	restoration interventions
Review and Approval	- Blockchain - BIM software	-Heritage Authorities -Project Manager	Blockchain ensures that all approvals are recorded and verified via multi-signature consensus	BIM model reflects feedback from stakeholders
Restoration Execution	BIM software	- Contractors - Engineers	Blockchain tracks ongoing restoration activities, logs modifications, and updates the ledger with timestamps	BIM model is updated with physical changes as restoration progresses
Continuous Monitoring and Reporting	- Blockchain - BIM software	- Project Manager - Contractors	Blockchain records continuous updates on restoration progress, ensuring data integrity and accountability	BIM model is used for monitoring and reporting project progress
Final Review and Documentation	BIM software	- Heritage Authorities - Auditors	Blockchain stores final approvals, inspections, and documentation, ensuring long-term preservation	Final BIM model serves as a permanent record of the restored structure
Long-Term Archival and Access	Blockchain	- Future Restorers - Archivists	Blockchain guarantees the immutability and long-term availability of project records	BIM model is archived, with references stored on blockchain for future access

The restoration workflow begins with the initiation phase, where a heritage structure is digitally captured through scanning technologies and modelled within a BIM environment, enriched with relevant metadata and historical context. In the proposal submission stage, restoration interventions are formally proposed, reviewed, and linked directly to the corresponding BIM elements. During blockchain logging, each submitted proposal or modification is immutably recorded on the blockchain, accompanied by digital signatures from responsible stakeholders to ensure accountability and traceability. The review and approval phase follows, in which authorized entities assess the proposals, a multi-signature consensus mechanism is employed to validate and authorize the proposed changes. Once approved, the process advances to the execution and monitoring stage, where physical interventions are carried out in alignment with the BIM model, which is continuously updated to reflect progress, each update recorded on-chain to preserve an auditable trail. Finally, in the archival phase, the completed BIM model, along with its associated decisions and restoration history, is permanently preserved as a verifiable, tamper-proof digital heritage record.

The proposed framework offers several key advantages that enhance heritage restoration practices. The combination of blockchain and BIM offers a unique set of advantages, interoperability, verifiability and scalability, that enhance their joint application in conservation project management. The model's interoperability can be achieved through a modular architecture that integrates with existing BIM platforms and diverse blockchain infrastructures, promoting broad adoption without the need for major system changes. Building on this foundation, verifiability is ensured by linking every action to a specific stakeholder and timestamp, creating full accountability and a tamper-proof audit trail. Designed with scalability in mind, the model can support a wide range of initiatives, from localized restorations of single buildings to large-scale national heritage programs. The framework supports long-term preservation, allowing future restorers and researchers to confidently trace the complete history of interventions, decisions, and structural changes through secure, immutable digital records. Comparison of BIM and blockchain capabilities in restoration is given in Table 4.

Tablo 4: Comparison of BIM and Blockchain Capabilities in Restoration

Feature	**BIM**	**Blockchain**	**Combined Advantage**	
Data Visualization	3D models of structures and interventions	-	BIM for modeling, blockchain for tracking model updates	-
Data Integrity	Prone to unauthorized edits without version tracking	Immutable, tamper-proof record	Ensures that BIM model history cannot be altered	Interoperability
Stakeholder Coordination	Centralized, may involve manual workflows	Decentralized, supports automated consensus (smart contracts)	Secure, rule-based collaboration	Interoperability
Audit Trail	Limited version control in many BIM tools	Full chronological trace of all transactions	Complete and verifiable restoration history	Verifiability
Legal & Compliance Documentation	Requires separate record-keeping and approvals	Records decisions and signatures on-chain	Streamlined, integrated documentation for legal verification	Scalability
Long-Term Preservation	Dependent on software compatibility and digital storage practices	Blockchain provides long-term verifiability	Durable digital preservation strategy	Verifiability

IV. DISCUSSION

The conceptual integration of BIM and blockchain technologies presents a vision for enhancing transparency, accountability, and data governance in heritage restoration. While each technology has demonstrated value independently within the AEC industries, their combined use in cultural heritage contexts remains underexplored. Stakeholder roles in the proposed integrated framework are presented in Table 5.

Tablo 5: Stakeholder Roles in the Integrated Framework

Stakeholder	Primary Responsibility	Type	Blockchain Role
Architects	Create and update HBIM model	Full BIM access	Sign model updates
Engineers	Technical assessments and interventions	Edit technical elements	Submit updates and maintenance records
Heritage Authorities	Regulatory oversight, compliance enforcement	Read-only or approval role	Approve key restoration decisions
Contractors	Execution of physical interventions	Limited BIM access	Log progress and activity reports
Historians/Archivists	Provide historical context and provenance validation	Metadata editing	Validate historical claims or provenance
Project Manager	Overall coordination and timeline management	Admin-level access	Oversee and sign off on all stages

One of the core contributions of blockchain is its ability to ensure trust in multi-stakeholder environments. In heritage restoration, where historical authenticity, data integrity and regulatory compliance are critical, immutable logs of decisions and interventions can serve as an auditable record for both current and future stakeholders. By anchoring changes made to the BIM model in a tamper-proof blockchain ledger, the framework provides a transparent and traceable system for managing interventions. This could mitigate disputes over unauthorized alterations, undocumented changes, or non-compliant actions.

Heritage restoration also involves extensive bureaucracy, requiring approvals from cultural ministries, preservation councils, and legal authorities. By implementing smart contracts within a permissioned blockchain environment, key actions such as material substitutions, structural reinforcements, or conservation techniques could be automatically validated once predefined conditions are met. This has the potential to reduce delays and administrative overhead while maintaining legal accountability and procedural correctness.

The preservation of heritage data should extend beyond physical restoration to include digital stewardship. BIM models risk becoming obsolete or corrupted over time due to file format changes or software incompatibility. Blockchain can complement BIM by acting as a durable verification system, where the authenticity of archived models and documentation can be validated years after a project is completed. This contributes to a future-proof digital heritage record, accessible to future restorers, scholars, and policymakers.

Despite its conceptual strengths, the proposed framework presents several challenges when applied in real-world contexts. One significant issue is technical interoperability, as current BIM software and blockchain platforms are not natively compatible. Bridging these systems would require the development of middleware solutions or custom APIs to ensure data exchange and functionality. Scalability is another concern directly storing full BIM datasets on the blockchain is impractical due to data size limitations, necessitating a hybrid approach where detailed files are kept off-chain and linked via cryptographic hashes. Additionally, cost and complexity pose barriers; implementing blockchain infrastructure can increase project expenses and demand specialized technical expertise, which may not be readily available in publicly funded or resource-constrained restoration projects. In addition, stakeholder readiness is critical, successful adoption hinges on the willingness of heritage authorities, architects, and contractors to adapt their workflows and place trust in decentralized, blockchain-based governance systems. These challenges highlight the importance of future research and pilot projects to assess practical feasibility and refine integration strategies.

Questions arise around who controls the historical narrative, who has authority to modify digital records, and how transparency balances with privacy. Blockchain's immutability, while valuable for trust, can also complicate error correction or sensitive data removal. While providing an immutable structure, it raises concerns when there are errors or incorrect data entries. To address these issues, careful governance, thorough testing, user training and validation control systems are necessary to mitigate risks and ensure data management in blockchain based systems. Careful governance models also need to be established to ensure ethical data management that aligns with heritage values and legal frameworks.

V. Conclusion and Recommendations

This study proposed a theoretical framework for integrating BIM and blockchain technologies in the heritage restoration. The goal is to address ongoing challenges to mitigate the challenges of authenticity and integrity in the field, such as lack of transparency, weak data governance, and fragmented collaboration among stakeholders. By combining the digital modelling capabilities of BIM with the immutable, decentralized structure of blockchain, the proposed model introduces a new paradigm for managing restoration projects with better accountability and long-term traceability.

The proposed framework provides several key advantages that enhance heritage restoration practices. Its interoperability allows better integration with existing BIM platforms and blockchain systems, making it adaptable to existing technologies. It ensures verifiability by associating each action with a specific stakeholder and timestamp, offering full accountability and a tamper-proof audit trail. The framework is also highly scalable for both small-scale restorations and large national heritage programmes. It also supports long-term conservation, ensuring that future restorers can confidently trace the history of interventions with immutable, digital records, thus preserving the authenticity, integrity and transparency of heritage management for future generations.

BIM serves as a powerful tool for representing historic structures and documenting interventions, while blockchain provides a trustworthy layer for validating and securing changes within a multi-stakeholder environment. This integration has the potential to enhance the technical accuracy of restoration processes and strengthen institutional and public trust in heritage conservation efforts. However, implementing such a framework is have some challenges. Issues such as system implementation costs, stakeholder resistance, and regulatory alignment must be addressed before real world adoption. Ethical concerns around data ownership, access control, and correction of historical records also require careful attention.

To advance the proposed framework from theory to practice, several key areas of future work are recommended. First, practical experiments and pilot implementations are essential to validate the framework's technical and organizational feasibility, particularly across diverse cultural, institutional, and geographic settings. Additionally, the development of open standards is critical to facilitate interoperability between HBIM platforms and blockchain systems, ensuring secure, consistent, and efficient data exchange. At the policy level, national and international heritage regulations need to evolve to recognize blockchain-based documentation as legally valid records within restoration and conservation processes. Moreover, widespread capacity building efforts including training programs, interdisciplinary workshops, and collaborative knowledge-sharing platforms should be established to equip heritage professionals, public authorities, and software developers with the skills and understanding required to adopt and adapt these emerging technologies effectively.

This conceptual work provides the basis for a more transparent, accountable and digitally resilient approach to heritage restoration. The proposed integration of BIM and blockchain supports current conservation needs and contributes to the long-term preservation of digital cultural heritage for future generations. Further empirical research and interdisciplinary collaboration will be essential in turning this vision into practical reality.

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