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Can blockchain prevent the deterioration of building handover information quality for higher education institutions?

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Abstract

Purpose – This research investigates the distinct characteristics of blockchain technology to safeguard against the deterioration of handover information quality in the post-construction phase. The significance of effective management of handover information is highlighted by global building failures, such as the Grenfell Tower fire in London, UK. Despite existing technological interventions, there remains a paucity of understanding regarding the factors contributing to the decline in the quality of handover information during the post-construction phase.

Design/methodology/approach – This study employed a multi-case studies approach across five higher education institutions. It involved conducting semi-structured interviews with 52 asset management professionals, uncovering the underlying reasons for the decline in handover information quality. Building on these insights, the study performed a mapping exercise to align these identified factors with blockchain technology features and information quality dimensions, aiming to evaluate blockchain's potential in managing quality handover information.

Findings – The study findings suggest that blockchain technology offers advantages but has limitations in addressing all the identified quality issues of managing handover information. Due to the lack of an automated process and file-based information exchange, updating handover information still requires an error-prone manual process, leading to potential information loss. Additionally, no solutions are available for encoding drawings for updates and validation.

Originality/value – This study proposes a framework integrating blockchain to enhance the information management process and improve handover information quality.

Keywords Handover information, Information quality, Asset information management, Blockchain technology, Higher education institutions

Paper type Research paper

1. Introduction

Inadequate information can introduce significant organisational inefficiencies, culminating in major financial challenges. Batini and Scannapieco (2016) highlight the severe financial repercussions of poor information quality. They point to the 2002 Data Warehousing Institute report, which revealed that US businesses suffered an annual loss exceeding

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$600bn due to inferior information quality (Eckerson, 2002). Similarly, the Architecture, Engineering and Construction (AEC) industry is not immune to these losses. Matarneh *et al.* (2019) highlighted that poor asset information management in the post-construction phase leads to an estimated annual loss of $10bn in the US building industry. Moreover, recent building failures linked to insufficient handover information management pose financial risks and further compromise the safety of occupants (Hackitt, 2017).

Handover information (HO) is the primary asset information source for the management of buildings (Pinheiro, 2019). Initially static, this information evolves dynamically in response to change throughout the building's lifecycle, requiring an effective information management solution (Leygonie, 2020). Investigations into various building failures have exposed the detrimental consequences of pervasive deficiencies in current building information management practices, leading to inaccurate, incomplete, and outdated information, which poses serious safety consequences (Hackitt, 2018; UK, 2022). Building Information Modelling (BIM) holds the potential to augment handover information quality. However, its application is predominately in new construction, which constitutes about only 1 to 2% of the total building stock annually (Roberts *et al.*, 2018). Consequently, BIM's information management capacity often bypasses pre-digital era constructions reliant on legacy information, which lacks transparency and accountability, especially in the verification of updates by stakeholders. With approximately 85% of the buildings in the European Union predating BIM, the importance of effective information management is significantly heightened (European Commission, 2020). This situation illuminates the urgency of addressing existing shortcomings in practices, particularly emphasising the vital importance of trustworthy handover information.

Blockchain technology, recognised for its potential to uphold the quality of handover information, offers a promising avenue for streamlining information exchange across various disciplines in a building project (Nawari and Ravindran, 2019). Blockchain is a decentralised ledger that records and shares every transaction within the network among its participants (Mukherjee and Pradhan, 2021). Blockchain has the potential to address prevalent issues in handover processes, such as insufficient record-keeping, inadequate paperwork furnished by contractors, and challenges in accessing information (Ali *et al.*, 2020). Its capacity to provide audit trails illuminates transparency and accountability (Mahmudnia *et al.*, 2022). Blockchain's transparency ensures a clear understanding of the ledger's status, enhancing participant accountability, while its traceability feature allows for the verification of information with accurate timestamps (Kshetri, 2017; Montecchi *et al.*, 2019). Offering a secure, uniform, and transparent approach, blockchain stands out as a suitable alternative to traditional centralised systems, improving the quality of the information (Love *et al.*, 2005).

Evaluating the features of blockchain in this context uncovers opportunities for innovation and improvement in information management within the higher education sector, posing the following research question:

> How can blockchain technology help prevent the deterioration of handover information quality for higher education institutions during the post-construction phase?

This study adopts a multi-case study approach, investigating higher education institutions across the UK, Ireland, Germany, and Northern Ireland. Motivated by prior research underscoring asset management inefficiencies due to subpar asset information quality in these institutions, it aims to devise information management strategies from their diverse building types, applicable to commercial buildings (Curvelo Magdaniel *et al.*, 2019; Syafar *et al.*, 2020). Semi-structured interviews with asset management professionals yielded nuanced insights into their perspective, completed by onsite observations for validations. A significant focus was a mapping exercise to explore blockchain's potential in addressing the fundamental causes of information quality decline. This study distinguishes itself from previous blockchain research by initially identifying specific evidence-based causes of information deterioration and then examining the suitability of blockchain for improvements. Its objective is to develop an empirically grounded solution to prevent the deterioration of handover information quality, particularly focusing on overcoming asset management challenges in the higher education sector.

This research is organised as follows. Section 2 reviews the literature on handover information in building management, information quality dimensions and characteristics of blockchain technology. Section 3 outlines the methodology for evaluating the potential of blockchain to prevent information quality decline. Section 4 proposes a blockchain information management framework, addressing the identified information deterioration causes. Section 5 discusses a critical analysis of the findings. Section 6 offers theoretical and practical contributions, discusses the research limitations, and suggests future research directions.

2. Literature review

This section discusses the relevant studies on the role of handover information in building asset management, the characteristics of information, and the features of blockchain technology. The literature review includes academic journals, conference papers, industry publications, and standards. This study follows the Data, Information, Knowledge and Wisdom (DIKW) hierarchy, positing that information is data that has been processed, organised, and contextualised (Frické, 2009).

2.1 The role of building handover information in building asset management

Upon completion of a building project, a comprehensive set of handover information is handed one-off to the asset owner, serving as the main data source about the project (Fang *et al.*, 2022; Pinheiro, 2019). This handover includes three information types: graphical, non-graphical, and project-related documentation (BSI, 2013). Graphical information generally encompasses as-built drawings and 3-dimensional models supported by the Building Information Modelling (BIM) (Chang *et al.*, 2022; Fang *et al.*, 2022). Non-graphical and documentation offer supplementary details, including operation and maintenance (O&M) manuals, product information, warranty certificates and testing reports, contributing to a holistic perspective of the building project (Cavka *et al.*, 2015; Chang *et al.*, 2022; Kassem *et al.*, 2015). The asset owners commonly dictate specific information requirements (BSI, 2013). Accordingly, contractors involved with a building project provide the required information during the handover phase (Zhu *et al.*, 2021).

Handover information is crucial for managing complex-built physical assets such as buildings, guiding regular maintenance and operational support to ensure the functionality and longevity of buildings (Chang *et al.*, 2022; Pinheiro, 2019). According to ISO 55000, this information is essential for a strategic, coordinated approach to managing multiple assets (Fang *et al.*, 2022; Petchrompo and Parlikad, 2019). This information also significantly impacts building energy simulations, improving energy efficiency and achieving sustainable development goals (Pinheiro, 2019). However, despite its importance, there is limited understanding of why the quality of handover information deteriorates.

2.2 The definition of information, its characteristics and information quality dimensions

The effective management of handover information demands understanding its nature, management perspective and quality standards. Information is processed data, can be repurposed without losing value yet may become outdated (Batini and Scannapieco, 2016; Mingers, 1996). Information management involves creating, acquiring, organising, storing, disseminating, and using information. Correspondingly, Wang *et al.* (1998) advise treating information like a manufactured product: recognising the specific needs of the information, managing the information as a product, overseeing the information throughout its lifecycle, and appointing dedicated roles to administer information. Concepts from manufacturing quality management can assess required quality attributes (Borek, 2012).

Quality information is commonly defined as information satisfying user requirements, categorised into four types (English, 1999; Wang and Strong, 1996). Wang and Strong (1996) proposed four categories of information quality: intrinsic, contextual, representational and accessibility data quality. Intrinsic quality focuses on accuracy and credibility, while contextual quality emphasises relevance and timeliness. Representational quality deals with ease of understanding, and accessibility quality concerns secure and easy access. English (1999) further classified the characteristics of dimensions into two broad categories: (1) Inherent information quality and (2) Pragmatic information quality. Inherent quality refers to data that can stand alone, such as "accuracy" and "non-duplication". Pragmatic quality focuses on meeting end-user needs, including "accessibility" and "usability".

Combining the English and Wang and Strong's approaches, the Data Management (DAMA) UK Working Group published six core quality dimensions, including the definitions and the related characteristics: (1) Completeness, (2) Uniqueness, (3) Timeliness, (4) Validity, (5) Accuracy, and (6) Consistency (UK DAMA, 2013). Therefore, this study adopts the DAMA's six primary quality dimensions to analyse the preferred quality characteristics of handover information.

(1) *Completeness:* All required data are present to meet the user's requirements

(2) *Uniqueness:* No data is recorded more than once

(3) *Timeliness:* All required data are sufficiently updated for the task

(4) *Validity:* All data conform to the syntax (e.g. format, type, etc.) within its definition

(5) *Accuracy:* Data correctly represent the actual value

(6) *Consistency:* The absence of difference when comparing two or more data sets

2.3 Blockchain for handover information management

With the expansion of quality principles into the Architecture, Engineering and Construction (AEC) industry, blockchain technology has emerged as a noteworthy candidate for the management of information quality. Blockchain and other forms of distributed ledger technologies (DLT) are databases of transactions hosted in a distributed network without a need for a central administrator (Perera *et al.*, 2020). A chain of blocks called the blockchain is created by grouping transactions into blocks, each containing a hash to the preceding block (Mukherjee and Pradhan, 2021). For a succinct overview, Table 1 summarises the salient features of blockchain relevant to information management, complemented by practical examples and implications.

Blockchain technology offers high transparency, traceability, and version control, serving as a reliable historical record-keeping system (Li and Kassem, 2021). Its core feature, distributed ledger technology (DLT) provides a single reliable source of information for all stakeholders by storing identical records across nodes to enhance the credibility of the information (Hijazi *et al.*, 2021). The decentralised nature of blockchain eliminates single points of failure, improving resilience and data integrity (Perera *et al.*, 2020). It also facilitates better data exchange, contributing to sustainability by ensuring transparent material and data origins (Shojaei *et al.*, 2019). Blockchain-based Material and Product Passports provide a trustworthy information source throughout the whole lifecycle of a built asset (Li and Wang,

	Feature	Example/Use	Reference
1	Single source of truth	Serving as an efficient historical record keeping system with version control of information models making the same data available to all stakeholders with the ability to read and write to the same ledger	Li and Kassem (2021), Hijazi *et al.* (2021), Penzes (2018)
2	Transparency	Material/Products Passports – providing sustainability through materials transparency and data provenance recording and managing modifications to an information model	Li and Kassem (2021), Perera *et al.* (2020), Hijazi *et al.* (2021), Penzes (2018), Wang *et al.* (2017)
3	Traceability	Recording all information (metadata including all product characteristics) to improve the lifecycle data provenance Keeping track of file versioning including documents, BIM models etc. Efficient tracking of provenance and movement of products through the supply chain	Li and Kassem (2021), Perera *et al.* (2020), Hijazi *et al.* (2021), Penzes (2018), Wang *et al.* (2017)
4	Immutability	Timestamped, tamper-proof, and immutable transactions on a blockchain network offer the possibility to enable a single source of reliable information ensuring data authenticity and compliance Detecting and removing any falsified information or attempts of tampering with data	Li and Kassem (2021), Perera *et al.* (2020), Hijazi *et al.* (2021), Penzes (2018)
5	Protection of IP rights	Ownership and intellectual property (IP) rights protection Models linked to the characteristics specified as IP can be granted access privileges via smart contracts, which can be used to monitor model authoring	Li and Kassem (2021), Hijazi *et al.* (2021)
6	Automation	Applications related to notarization that reduce the time required for verifying the authenticity of documents Automated payments triggered by completed tasks and deliverables Automated procurement Automated compliance and evaluation of compliance	Li and Kassem (2021), Hijazi *et al.* (2021), Penzes (2018), Wang *et al.* (2017)
7	Data longevity and resilience	Independence from software providers as data is immutable and will be stored on the blockchain as long as it exists Storing information for the whole lifecycle of an asset (even 50+ years)	Perera *et al.* (2020), Shojaei, (2019)
8	Decentralisation	Lack of central administrator or centralised data storage mechanism. Decentralisation offers resilience while minimising many-to-one traffic flows to prevent delays and single points of failure Hindering data tempering be the central party managing the data	Kinnaird and Geipel (2017), Perera *et al.* (2020)

(*continued*)

Table 1. Principles of blockchain

	Feature	Example/Use	Reference
9	Security	Encryption techniques used by blockchain ensure the accuracy of the data recorded and eliminate fraud Private information may be kept confidential by using encryption, while digital signatures provide assurances of validity, integrity of information, and non-repudiation	Perera *et al.* (2020), Penzes (2018)
10	Anonymity	As public and private keys are utilised in blockchain transactions, individuals may decide to remain anonymous to safeguard their privacy while allowing other parties to validate their identity. This makes it possible to preserve and protect the confidentiality of transactions	Perera *et al.* (2020)

Table 1.

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2021). Security is another strong suit: data manipulation is nearly impossible as changes must be made across all nodes and blocks (Mukherjee and Pradhan, 2021). The technology employs consensus mechanisms and public-key cryptography to maintain data integrity and privacy (Perera *et al.*, 2020). One of the most fundamental features is smart contracts, self-executing codes that operate without intermediaries once set conditions are fulfilled (Mukherjee and Pradhan, 2021). These contracts foster trust among stakeholders (Kim *et al.*, 2020). However, there have yet to be validation studies that confirm the acclaimed benefits of blockchain technology in managing asset information, including handover information (Wang *et al.*, 2017).

2.4 Applications of blockchain in the AEC industry

Several studies showcase the applications of blockchain's versatility, particularly its problem-solving capabilities rooted in payment systems, collaboration and documentation, throughout various stages of a building's lifecycle (Li and Kassem, 2021; Mahmudnia *et al.*, 2022). In the design phase, the blockchain's immutable record-keeping feature tracks all design changes, streamlining the design collaborative coordination process to minimise ambiguities in design documents (Di Giuda *et al.*, 2020). Moreover, blockchain applications extend to improving supply chain management and progress payments in construction to avoid construction delays (Ahmadisheykhsarmast and Sonmez, 2020; Qian and Papadonikolaki, 2020). Beyond construction, Götz *et al.* (2020) advocate leveraging blockchain for documenting post-construction operational data and information, ensuring the preservation of essential information for future use and complying with the legal duties of operating buildings (Li *et al.*, 2019).

2.5 The gap of knowledge in quality handover information management

The review of the literature reveals a knowledge gap in using blockchain technology for managing building handover information. Three main issues exist. Firstly, there is a dearth of discussion on integrating dynamic information characteristics with blockchain technology to manage trustworthy handover information. Secondly, the potential of blockchain technology is often highlighted without empirical evidence, particularly in the AEC industry, that illustrates its practical use or detailed analyses. Lastly, the relationship between specific quality concerns in handover information and the limitations of blockchain-based handover information management remains unexplored. Consequently, a new study is needed to assess the feasibility of blockchain in addressing the identified quality concerns, offering a fresh outlook on the issue of "rich" information but "poor" quality.

3. Methodology

This research adopted a multi-case strategy to assess the feasibility of blockchain in preventing handover information quality corrosion. Following Yin's (2018) recommendation, this research leveraged a case study approach for real-life insights, with comparative analysis enhancing the robustness of findings. This study combined semi-structured interviews and direct site observations to corroborate the participants' input. The investigation progressed in three phases: a narrative literature review identified frameworks and methodologies related to handover information management, information quality management in the AEC industry, and blockchain for managing construction-related information. Next, five case studies with higher education institutions explored the causes of the quality deterioration in handover information in the post-construction phase. The final phase evaluated the potential of blockchain in addressing the identified causes.

3.1 Case selection

This study adopted a case-based approach for in-depth investigations in a real-world context, ideal for small sample sizes (Patton, 1999; Saunders *et al.*, 2019). The study strategically focuses on the higher education sector to derive information management strategies from its varied building functions, which can be applicable to a wide range of commercial buildings. Guided by Miles *et al.* (2018), this study developed the following selection criteria.

(1) *Type of sector:* Higher education institutions,

(2) *Type of physical assets:* Portfolios of buildings of various ages and different uses,

(3) *Type of process:* The use of handover information to support asset management processes.

The appropriate number of cases for multi-case study research is a debated topic. Nonetheless, this study followed the widely accepted principle of theoretical saturation for determining the optimal number of cases, as suggested by Eisenhardt (1989). This study selected cases from various countries to avoid contextual biases. Chosen organisations use globally recognised technological tools for managing handover information and adopt the International Organisation for Standardisation (ISO) 55,000 standards to manage their physical assets. Profiles of the selected cases are detailed in Table 2.

3.2 Data collection and analysis

This study involved conducting semi-structured interviews with participants from each case, primarily aimed at gaining a comprehensive understanding of the following aspects.

(1) *Organisational structure:* Defining the roles and responsibilities within the Estates Division.

(2) *Process:* Streaming the flow of handover information pertaining to various projects.

(3) *Utilisation:* The use of handover information and its quality requirements.

(4) *Management:* The use of asset information management systems.

Table 2.
Summary of the selected cases

Case study	Description	Country
1	This public collegiate research university was founded circa 1,209 in the United Kingdom. Its extensive grounds include a diverse collection of over 1,000 buildings spanning various architectural styles. These encompass libraries, museums, research labs, teaching facilities and vast stretches of land. With a history of over 800 years, the institution showcases a blend of traditional and cutting-edge facilities. The university has implemented over ten asset information management systems to manage various handover information, including drawings and non-graphical data. The university is considering consolidating these existing systems into a unified platform-based solution, streamlining the management of handover information	UK
2	The university was founded in Ireland in 1,592 and comprises 67 traditional and innovative buildings. These buildings are located across 13 different areas, covering approximately 108 acres of land. While some buildings date back to the early 1700s, the university continues investing in modern and advanced facilities. The university has recently employed an external architectural firm to update and enhance the accuracy of as-built drawings. This is to address ongoing building management issues and optimise the use of physical spaces. Given the significance of streamlined asset information management, it is presently implementing a unified platform-based solution for asset information as a proactive measure	Ireland
3	This public research university, with its roots dating back to 1843, was established in the United Kingdom in 1992. The main campus occupies a 33-acre site with over 100 buildings that are equipped with state-of-art research and teaching facilities. The university also has remote locations in the UK, including oversea campus, which are strategically utilised through leased spaces. Adopting digital solutions early on, the university has effectively managed its buildings, leveraging various sensors to optimise the utilisation of physical spaces. Continuous efforts are underway to improve the accuracy of asset information, including building handover information to support informed decision-making	UK
4	This university attained university status in 1908, but its origins can be traced back to 1810 in Northern Ireland. The college campus spans approximately 113 acres and features about 100 buildings of varying ages and purposes. Consequently, the university handles various physical and digital handover information. Given the importance of physical space management, the university employs an integrated system solution. This solution effectively manages the physical space across the entire campus and is supported by dedicated resources responsible for consistently monitoring and updating space utilisation	Northern Ireland
5	Situated in Germany, this college campus expands substantially and houses six major departments, including physics, chemistry, and different engineering disciplines. In the 1960s, these departments were relocated from the city centre to their current location. Since then, the campus has undergone continuous development, fostering collaboration with industry partners to construct state-of-art research facilities. However, the use of asset information systems is unclear, and each department has limited access to building handover information	Germany

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Table 3 lists 52 participants from five cases, all regular users of handover information in their job duties. Each interview spanned between 60 and 90 min. With the consent of the participants, interviews were recorded and transcribed to ensure accuracy and transparency.

Cases	Participants	Disciplines in asset management	Location
1	C1_P1	Space Management	UK
	C1_P2	Property Insurance	UK
	C1_P3	Vertical Transportation Systems	UK
	C1_P4	Electrical Systems	UK
	C1_P5	Heating and Ventilation Systems	UK
	C1_P6	Water Quality	UK
	C1_P7	Maintenance Management	UK
	C1_P8	Compliance Management	UK
	C1_P9	Asset Infor Management (O&M)	UK
	C1_P10	Estates Management	UK
	C1_P11	Maintenance Record Management	UK
	C1_P12	Compliance Management	UK
	C1_P13	Capital Projects	UK
	C1_P14	Capital Projects	UK
	C1_P15	Estates Management	UK
	C1_P16	Asset Registry	UK
	C1_P17	Change Management (Outsourcing)	UK
	C1_P18	Asset Information Systems (IT)	UK
	C1_P19	Estates Management Records	UK
	C1_P20	Capital Projects (HO Info)	UK
	C1_P21	Capital Projects (HO Info)	UK
	C1_P22	Asset Info Management	UK
	C1_P23	Asset Info Management	UK
	C1_P24	Business Processes	UK
	C1_P25	Compliance Management	UK
	C1_P26	Asset Info Management	UK
2	C2_P1	Space Management	Ireland
	C2_P2	Property Insurance	Ireland
	C2_P3	Fire Systems	Ireland
	C2_P4	Asset Information Systems	Ireland
	C2_P5	Mechanical and Electrical Systems	Ireland
	C2_P6	Estates Management	Ireland
	C2_P7	Water Quality	Ireland
3	C3_P1	Space Management	UK
	C3_P2	Mechanical and Electrical Systems	UK
	C3_P3	Mechanical and Electrical Systems	UK
	C3_P4	Estates Management	UK
4	C4_P1	Campus Planning and Space Management	N. Ireland
	C4_P2	Space Management	N. Ireland
	C4_P3	Property Insurance	N. Ireland
	C4_P4	Mechanical and Electrical Systems	N. Ireland
	C4_P5	Water Quality	N. Ireland
	C4_P6	Handover Information Management	N. Ireland
	C4_P7	Asset Info Management (O&M)	N. Ireland
	C4_P8	Fire, Life and Safety Systems	N. Ireland
	C4_P9	Capital Projects	N. Ireland
5	C5_P1	Space Management	Germany
	C5_P2	Fire, Life and Safety Systems	Germany
	C5_P3	Mechanical, Electrical and Fire Systems	Germany
	C5_P4	Mechanical and Electrical Systems	Germany
	C5_P5	Mechanical and Electrical Systems	Germany
	C5_P6	Space Management (Portfolio Planning)	Germany

Source(s): Created by authors

Table 3.
Participant profiles

Participants received interview transcripts for review and verification, enhancing the study's reliability.

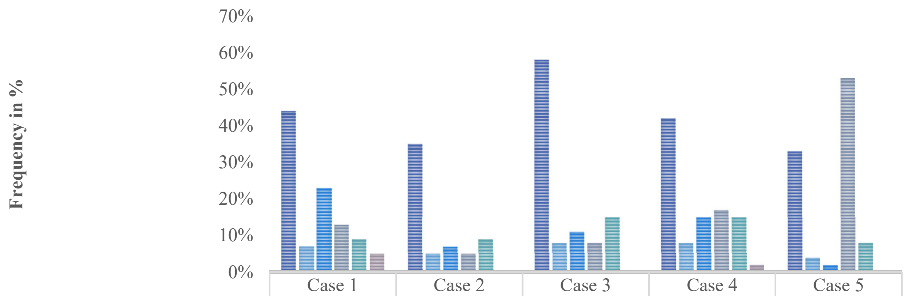
This research adopts an inductive approach. NVivo, a qualitative data analysis software, analysed interview data to understand the handover information quality decline (Miles *et al.*, 2018). After thematic analysive, the Root Cause Analysis (RCA) technique pinpointed the root causes of quality corrosion. A comprehensive cross-case analysis provided further insights. These causes were then compared with blockchain technology characteristics to assess its potential in addressing these issues, leading to the proposition of a blockchain-based framework, utilising smart contracts for updating and validating handover information.

4. Findings

4.1 The results of comparative analysis

This section provides six root causes of the handover information quality deterioration across five cases, determined through thematic analysis: (1) irregular handover information management, (2) evolving technology leading to heterogeneous formats, (3) information loss, (4) exogenous factors, (5) human errors, and (6) leadership impacts. Figure 1 was also created based on the occurrences of the reported issues from each case. The purpose of this figure is not to make statistical inferences but to compare the reported problems visually.

4.1.1 Irregular handover information management. The findings across cases consistently demonstrate that irregular management processes for handover information affect the quality of the handover information, as stressed by Woodall *et al.* (2013). Each case identified two primary sources of handover information: major (e.g. new projects, extensive renovations) and minor projects (e.g. equipment replacement). Despite the sources of handover information, "*the information management process is a bit fluid*" and "*separate information is sitting all over the place in a central information management system*" without understanding the intended use of the information (C1_P1 and C1_P20). As a result, "*it is a challenge to get 'accurate' and 'up-to-date information'* (C1_P1, C1_P2 and C1_P19)". Moreover, C4_P1 argues that a lack of information flow of "*lots of minor works and projects across the campus becomes problematic*". Supplementally, "*the issue here in terms of handover documentation is to do with multiple small projects*" without understanding the roles and



	Case 1	Case 2	Case 3	Case 4	Case 5
HO Info Management Process	44%	35%	58%	42%	33%
Data loss	7%	5%	8%	8%	4%
External Factors	23%	7%	11%	15%	2%
Organisational Issues	13%	5%	8%	17%	53%
Human Factors	9%	9%	15%	15%	8%
Technology	5%	0%	0%	2%	0%

Source(s): Created by authors

Figure 1.
Comparative analysis of case studies

responsibilities of managing such information (C1_P20). In aligning this view, C2_P4 and C4_P4 confirm that "*we need to have 'robust procedures*' for handling handover information for minor projects".

4.1.2 Evolving technology leading to heterogeneous formats for as-built drawings. All cases manage buildings of diverse ages, and most buildings predate the AutoCAD era. As a result, each case manages as-built drawings in different formats, which have been predominately influenced by evolving technological advancements in the AEC industry (Love *et al.*, 2018). The recent adoption of BIM has introduced additional non-conventional formats, particularly for drawings such as 3-dimensional models and IFC files. Consequently, "*we have varieties of as-built formats, including hard copies, mylars and blueprints, AutoCAD files, and Revit models*"(C3_P4). In earlier days, the "*physical drawings were scanned without considering the risk of altering the original scale of the drawings*", but the modified scaled drawings are solely intended for schematic viewing (C1_P18, C4_P2 and C5_P1). Dissimilar formats frequently require "conversion" to useful formats (C1_P1). The quality consequences of using as-built drawings in multiple formats are presented in the following section.

4.1.3 Information loss. The analysis indicates that information loss is twofold. As previously mentioned, diverse formats of drawings contribute to information loss, especially when converting the existing formats to useful formats. For example, "*when we transfer the drawings from CAD files to a PDF format, then obviously we lose some of the detail and richness behind the CAD plans*" (C2_P1). Similarly, "*when we convert 3D models into 2D plans, we lose the richness of information embedded in the 3D models. At the same time, we lose some information when converting from 2D plans to 3D models*" (C4_P2).

Another contributing factor to information loss is the gradual erosion of the vital handover information, as Yilmaz and McFarlane (2015) pinpointed. Physical documents are susceptible to "*misplacement*", "*damage*", and "*deterioration*", further exacerbating critical information erosion over time (C1_P9, C3_P4 and C5_P2). For example, older buildings tend to have less comprehensive information than newer construction. C2_P6 added, "*we have fewer than 10 sheets of drawings for the 200-year-old structure, while the BIM-based projects provide an unparalleled volume of handover information*". This disparity is attributed to "*outdated documentation practices*" and "*insufficient record-keeping systems*" prevalent during earlier times (C4_P9 and C5_P6). Further, the mismanagement of handover information is compounded by "*the absence of standardised procedures*" for managing such information and the inadequate implementation of information migration strategies when adopting new technological solutions (C1_P18).

4.1.4 External factors. Continuous updates in building regulations and relevant requirements often give rise to confusion and inconsistencies when gathering essential handover information. This, in turn, leads to incomplete information and the possibility of errors (C1_P25, C2_P3, C2_P7, C4_P4 and C4_P9). For instance, the fire, life, and safety systems have progressively advanced over the years (C2_P3 and C4_P8). These evolving updates create a situation where asset owners lack a comprehensive understanding of the information and adequate information, which hampers the quality of the handed-over information. Furthermore, the intricate nature of compliance measures and reporting obligations can pose challenges in compiling accurate and complete information (C1_P25). These complexities can overshadow meticulous documentation practices, resulting in a decline in the quality of the handover information (C1_P26, C4_P4 and C5_P3).

While effective documentation practices are instrumental in improving the quality of handover information, the existing AEC industry has yet to develop dedicated digital tools for managing legacy handover information (C1_P11, C1_P15 and C1_P18). Many buildings predating the AutoCAD era continue to rely on numerous physical files, outdated formats, and disorganised records for their management. These physical documents are prone to misplacement, damage, or even destruction, directly impacting the information's quality.

Concurrently, legacy information collides with digitally formatted handover information (C2_P4, C3_P4 and C5_P6). As a partial solution, a platform-based approach is commonly adopted for storing and exchanging file-based information, but this solution requires converting physical documents into useable formats (C4_P7). As mentioned earlier, the integrity of documents can be altered during the conversion process, limiting the future use of information.

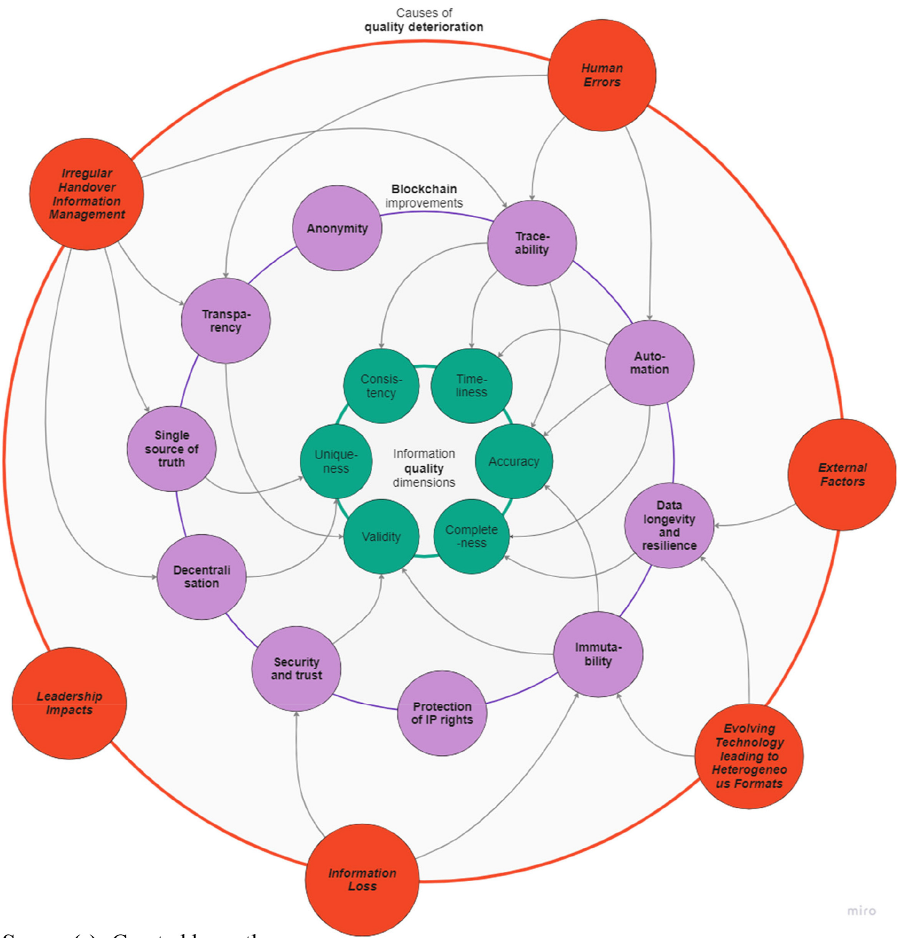
4.1.5 Human errors. Handover information may suffer from negative impacts due to human errors and mistakes, even those that seem minor or insignificant (C1_P1, C2_P1 and C4_P1). One commonly reported error was the improper distribution of handed-over information to incorrect asset information management systems or information depositories. This mistake often results in the loss of valuable information as the intended information ends up in the wrong location (C1_P1, C1_P21 and C3_P3). Recurring mistakes were observed in incorrectly tagging equipment and components (Yilmaz and McFarlane, 2015). This led to inaccurate labelling and categorisation of items, causing additional resources and time-consuming processes for verification, particularly for insurance inspections. Moreover, the data entry errors in the asset information system had significant consequences. For instance, incorrectly naming a building or using the wrong address resulted in information loss, inefficiencies in retrieving information, and potential safety risks for occupants in emergencies.

4.1.6 Leadership impacts. The absence of leadership support hinders the quality of handover information. This is mainly due to leaders not understanding the role of handover information in the post-construction phase. Their failure to see its importance makes it hard to allocate resources and implement effective strategies to improve the management approach, ultimately affecting the quality. The lack of leadership support is a major obstacle to achieving high-quality handover information. Without garnering support from leaders, the value and use of this information are often overlooked, leading to mismanagement (Masood *et al.*, 2016). This misunderstanding negatively impacts the efficiency after construction. Educating leaders about the crucial role of handover information can ensure smooth post-construction operations, as indicated by all cases (C1_P20, C2_P15, C4_P4, C7_P2 and C7_P3).

The comparative analysis identified six underlying reasons behind the quality decline in handover information, notably irregular information management processes and information loss. Additionally, the quality of as-built drawings was evaluated in light of technological advancement, while human errors and lack of leadership support contributed to the quality deterioration. However, the quality effects caused by external factors remain unexplored in current research. In the following section, the identified root causes are mapped against the characteristics of blockchain technology to explore the potential of blockchain in addressing quality dilemmas.

4.2 Mapping of blockchain characteristics to root causes

Figure 2 illustrates the mapping of quality issues, blockchain features and the six core information quality dimensions identified in the literature (UK DAMA, 2013). The mapping exercise aims to illustrate the possibilities of addressing quality issues (as shown in the outer circle) correlates with the characteristics of blockchain, which are represented in the middle circle of the diagram. The cross-analysis of the case study revealed that inconsistent handover information management during the post-construction phase hugely affects the quality of handover information. This specific cause was mapped to the corresponding blockchain features identified in the literature: "single source of truth", "transparency", "traceability", and "decentralisation". For example, defining roles and responsibilities for managing handover information can be enhanced by well-defined smart contracts,



Source(s): Created by authors

Figure 2.
Mapping of root causes, blockchain attributes and data quality dimensions

increasing the transparency of stakeholders' tasks and activities. All submitted documents will be recorded in an immutable manner, enabling to trace the information as long as the blockchain exists. Moreover, the decentralised concept of managing documents removes one controlling party revising the documents. Combining these attributes will achieve a "single source of truth" for asset information to support the future use of buildings.

Subsequently, the blockchain features are connected to the relevant information quality attributes of information quality in the handover information, which is displayed in the central circle of the figure. For example, completeness of information would be ensured by providing a blockchain-based historical record of all transactions and by incorporating smart contracts to detect incomplete information. Blockchain ensures uniqueness as it provides a single source of truth for all participating nodes. Keeping track of all versions of the files and their metadata provides data timeliness, accuracy, and validity, which is strengthened even more by the immutability of blockchain records. The consistency of data records is ensured by smart contracts validating if the information is classified correctly.

In the mapping exercise, leadership impact was not mapped to any characteristics of blockchain. The leadership impact caused by the quality deterioration of handover information is not an isolated cause, but support from leadership is necessary to realise the full benefits of implementing blockchain technology to prevent the quality decline. Features like "anonymity" and "protection of IP rights" were also not mapped because these features are irrelevant to the handover information management. This exercise culminated in a proposed conceptual framework for managing handover information irrespective of project size as the asset owners update different assets.

4.3 Framework proposal

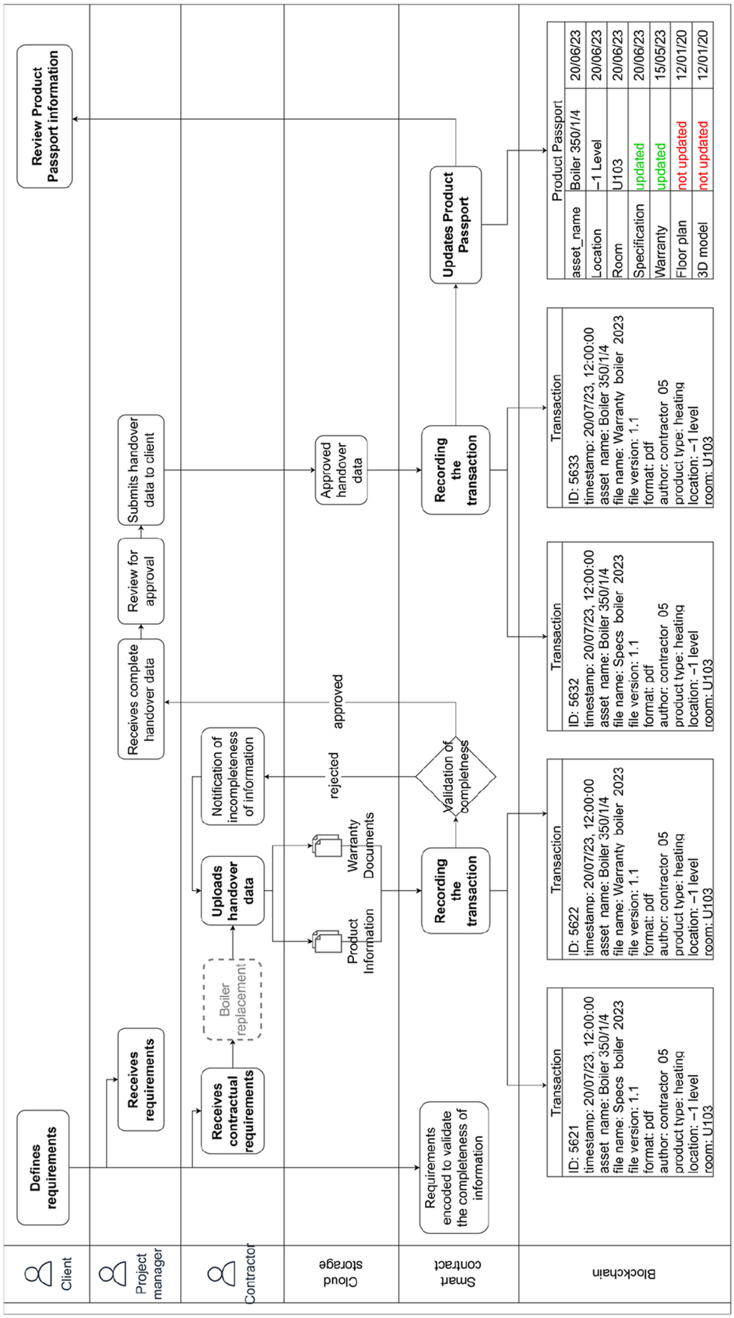
Leveraging blockchain's benefits, a conceptual framework is proposed for gathering handover information using blockchain and smart contracts (Figure 3). The process begins with the client defining handover information requirements, which are then encoded into a smart contract. This contract validates the completeness of information uploaded by the contractor. Once the construction phase concludes, the contractor submits the handover information to the selected cloud platform designated by the client. A smart contract, communicating with the Application Programming Interface (API), records transaction metadata on the blockchain and checks the information against the encoded requirements. If any information is missing, smart contract will notify the contractor to re-upload the necessary information. After the smart contract confirms the completeness of the submitted information, it forwards the submitted documents to the architect for review. Once approved, the final documents are submitted to the client. This general framework facilitates both major and minor projects during the post-construction phase of a built asset.

Furthermore, the example illustrates the use of blockchain and smart contracts in streamlining the update of handover information in a minor project. In the scenario, a contractor replaces a boiler and consequently updates the product specification and warranty documents in the cloud-sharing platform selected by the client. The metadata of the updated information is recorded on the blockchain by the smart contract, which also updates the information in the product passport. For graphical information, such as 2D drawings or 3D models, current technology does not allow encoding the validation of drawings as part of the smart contract, which limits updating in the product passport. Therefore, the client will observe that the drawings or 3D models related to the replacement units are missing from the product passport review.

5. Discussion

The investigation into handover information management reveals that robust information management is pivotal to maintaining the integrity and quality of information. These findings align with Masood *et al.* (2016), who underscores the critical role of uniform information management processes in ensuring the long-term quality of information. Further compounding these issues, Yilmaz and McFarlane (2015) pinpoint the tangible risks associated with physical information loss and the adverse effects of outdated and ineffective record-keeping methods on the quality of handover information.

Transitioning to the broader context, information is constantly evolving through major and minor projects, ranging from extensive renovations to equipment replacements. Each project represents a transactional update event, where accuracy is critical to prevent cascading issues. Love *et al.* (2018) stress the importance of precision in maintaining as-built drawings. Despite the critical nature of managing transactional updates, the task of updating graphical information and corresponding non-graphical information remains vulnerable, mainly due to its reliance on manual updates. This vulnerability stems from the ingrained



Source(s): Created by authors

Figure 3.
A conceptual blockchain framework of handover information collection process

nature of asset information management in current workflows. Further, there is a notable knowledge gap concerning the effects of poor legacy information management and the assimilation of evolving regulatory demands on the quality of information. This indicates underlying systemic issues in information governance, extending beyond technological solutions.

Viewed through this transactional lens, blockchain emerges as a potential, though not originally developed as an information management tool. Blockchain addresses specific concerns, such as immutability and decentralisation, which are highly relevant to asset information management. While blockchain cannot create new information or rectify digitalisation errors, it offers a reliable mechanism for tracking the provenance and changes made to asset information. Over time, this could lead to the creation of more reliable information. Furthermore, blockchain's immutable nature ensures that every transaction is recorded with the necessary quality for managing the long lifespan of buildings. The adoption of Distributed Ledger Technology (DLT) like blockchain could markedly improve the efficiency in the detailed documentation and tracking of updates with foundational trust in business relationships, especially in the AEC industry (Qian and Papadonikolaki, 2020).

It is noteworthy to state that blockchain's security feature is significant, yet this study indicates asset management professionals, especially in higher education, may underemphasise security concerns. Parn and Edwards (2019) stressed the need to harness blockchain's security for protecting assets in high-risk environments, such as banks, prisons, and defence facilities. Although resilient, blockchain is not impervious to threats. Yli-Huumo *et al.* (2016) raised a cautionary note about vulnerabilities, such as the "51% attack", where control over half of the network could lead to blockchain manipulation. This risk illuminates the necessity for vigilant management and robust strategies when implementing blockchain technology.

In sum, it is critical to weigh blockchain's benefits against its limitations and consider its function in an extensive operational context. Key aspects include fostering trust and developing an integrated strategy to handle assets' amassed digital and physical information. Utilising blockchain to enhance transactional and provenance tracking in asset management can significantly improve information quality.

6. Conclusions

This research's evidence-based case study approach identified the root causes of handover information quality deterioration based on multiple cases. A blockchain-based framework was then proposed to improve the management of handover information, aligning the identified root causes with blockchain features and information quality dimensions. This approach, not presented in previous studies, highlights the unique challenges and limitations of implementing blockchain technology in the management of asset information, including building handover information.

This study offers theoretical and practical contributions. On a theoretical level, it positions blockchain technology as a potentially disruptive innovation yet acknowledges its limitations in fully addressing the complexities of handover information management. It challenges the assumption that blockchain can entirely overhaul existing information flows and associated processes in the cases studied.

Practically, the study provides managers and practitioners with a framework to improve the quality of the handover information management process using blockchain technology. The study highlights the need for organisations to tailor blockchain solutions to their specific needs, ensuring effective enhancement of the information quality. The research underscores the importance of bespoke strategies in integrating blockchain technology to prevent quality deterioration in handover information, illuminating the practical implications.

Building on vital insights from asset management professionals, this study proposes a conceptual framework for managing handover information. However, this study poses certain limitations. Its scope is narrowly confined to information management in asset management, excluding a facilities management perspective. A notable challenge identified is the extensive outsourcing of facilities management tasks in the participating organisations, a trend noted by Adhikari *et al.* (2019). Consequently, future research is essential to evaluate blockchain's productivity and cost-benefits for developing a refined prototype or proof of concept. Such research is crucial for a broader scale, including by third-party service contractors accessing and updating asset information.

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