

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

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 \$600 billion 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 \$10 billion 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 per cent 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.

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3 77 This research is organised as follows. Section 2 reviews the literature on handover information in building
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5 78 management, information quality dimensions and characteristics of blockchain technology. Section 3 outlines
6
7 79 the methodology for evaluating the potential of blockchain to prevent information quality decline. Section 4
8
9 80 proposes a blockchain information management framework, addressing the identified information
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11 81 deterioration causes. Section 5 discusses a critical analysis of the findings. Section 6 offers theoretical and
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13 82 practical contributions, discusses the research limitations, and suggests future research directions.
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15

16 17 83 **2 Literature review**

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20 84 This section discusses the relevant studies on the role of handover information in building asset management,
21
22 85 the characteristics of information, and the features of blockchain technology. The literature review includes
23
24 86 academic journals, conference papers, industry publications, and standards. This study follows the Data,
25
26 87 Information, Knowledge and Wisdom (DIKW) hierarchy, positing that information is data that has been
27
28 88 processed, organised, and contextualised (Frické, 2009).
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31 89 2.1 The role of building handover information in building asset management

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33
34 90 Upon completion of a building project, a comprehensive set of handover information is handed one-off to the
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36 91 asset owner, serving as the main data source about the project (Fang *et al.*, 2022; Pinheiro, 2019). This
37
38 92 handover includes three information types: graphical, non-graphical, and project-related documentation (BSI,
39
40 93 2013). Graphical information generally encompasses as-built drawings and 3-dimensional models supported
41
42 94 by the Building Information Modelling (BIM) (Chang *et al.*, 2022; Fang *et al.*, 2022). Non-graphical and
43
44 95 documentation offer supplementary details, including operation & maintenance (O&M) manuals, product
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46 96 information, warranty certificates and testing reports, contributing to a holistic perspective of the building
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48 97 project (Cavka *et al.*, 2015; Chang *et al.*, 2022; Kassem *et al.*, 2015). The asset owners commonly dictate
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50 98 specific information requirements (BSI, 2013). Accordingly, contractors involved with a building project
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52 99 provide the required information during the handover phase (Zhu *et al.*, 2021).
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56 100 Handover information is crucial for managing complex-built physical assets such as buildings, guiding regular
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58 101 maintenance and operational support to ensure the functionality and longevity of buildings (Chang *et al.*,
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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,

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2
3 128 2013). Therefore, this study adopts the DAMA's six primary quality dimensions to analyse the preferred
4
5 129 quality characteristics of handover information:

- 8 130 • Completeness: All required data are present to meet the user's requirements
- 10 131 • Uniqueness: No data is recorded more than once
- 12 132 • Timeliness: All required data are sufficiently updated for the task
- 14 133 • Validity: All data conform to the syntax (e.g., format, type, etc.) within its definition
- 16 134 • Accuracy: Data correctly represent the actual value
- 18 135 • Consistency: The absence of difference when comparing two or more data sets

22 136 2.3 Blockchain for handover information management

25 137 With the expansion of quality principles into the Architecture, Engineering and Construction (AEC) industry,
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27 138 blockchain technology has emerged as a noteworthy candidate for the management of information quality.

29 139 Blockchain and other forms of distributed ledger technologies (DLT) are databases of transactions hosted in a
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31 140 distributed network without a need for a central administrator (Perera *et al.*, 2020). A chain of blocks called
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33 141 the blockchain is created by grouping transactions into blocks, each containing a hash to the preceding block
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35 142 (Mukherjee and Pradhan, 2021). For a succinct overview, **Table I** summarises the salient features of
36
37 143 blockchain relevant to information management, complemented by practical examples and implications.

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41 144 Blockchain technology offers high transparency, traceability, and version control, serving as a reliable
42
43 145 historical record-keeping system (Li and Kassem, 2021). Its core feature, distributed ledger technology (DLT)
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45 146 provides a single reliable source of information for all stakeholders by storing identical records across nodes
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47 147 to enhance the credibility of the information (Hijazi *et al.*, 2021). The decentralised nature of blockchain
48
49 148 eliminates single points of failure, improving resilience and data integrity (Perera *et al.*, 2020). It also
50
51 149 facilitates better data exchange, contributing to sustainability by ensuring transparent material and data origins
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53 150 (Shojaei *et al.*, 2019). Blockchain-based Material and Product Passports provide a trustworthy information
54
55 151 source throughout the whole lifecycle of a built asset (Li and Wang, 2021). Security is another strong suit:
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57 152 data manipulation is nearly impossible as changes must be made across all nodes and blocks (Mukherjee and
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3 153 Pradhan, 2021). The technology employs consensus mechanisms and public-key cryptography to maintain
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5 154 data integrity and privacy (Perera et al., 2020). One of the most fundamental features is smart contracts, self-
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7 155 executing codes that operate without intermediaries once set conditions are fulfilled (Mukherjee and Pradhan,
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9
10 156 2021). These contracts foster trust among stakeholders (Kim *et al.*, 2020). However, there have yet to be
11
12 157 validation studies that confirm the acclaimed benefits of blockchain technology in managing asset
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14 158 information, including handover information (Wang *et al.* 2017).

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17 159 **Table I Principles of blockchain.**

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19 160
20 161 2.4 Applications of blockchain in the AEC industry

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23 162 Several studies showcase the applications of blockchain's versatility, particularly its problem-solving
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25 163 capabilities rooted in payment systems, collaboration and documentation, throughout various stages of a
26
27 164 building's lifecycle (Li and Kassem, 2021; Mahmudnia *et al.*, 2022). In the design phase, the blockchain's
28
29 165 immutable record-keeping feature tracks all design changes, streamlining the design collaborative
30
31 166 coordination process to minimise ambiguities in design documents (Di Giuda *et al.*, 2020). Moreover,
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33 167 blockchain applications extend to improving supply chain management and progress payments in construction
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35 168 to avoid construction delays (Ahmadisheykhsarmast and Sonmez, 2020; Qian and Papadonikolaki, 2020).
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37
38 169 Beyond construction, Götz *et al.* (2020) advocate leveraging blockchain for documenting post-construction
39
40 170 operational data and information, ensuring the preservation of essential information for future use and
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42 171 complying with the legal duties of operating buildings (Li *et al.*, 2019).

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44
45 172 2.5 The gap of knowledge in quality handover information management

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47
48 173 The review of the literature reveals a knowledge gap in using blockchain technology for managing building
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50 174 handover information. Three main issues exist. Firstly, there is a dearth of discussion on integrating dynamic
51
52 175 information characteristics with blockchain technology to manage trustworthy handover information.
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54 176 Secondly, the potential of blockchain technology is often highlighted without empirical evidence, particularly
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56 177 in the AEC industry, that illustrates its practical use or detailed analyses. Lastly, the relationship between
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58 178 specific quality concerns in handover information and the limitations of blockchain-based handover
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3 179 information management remains unexplored. Consequently, a new study is needed to assess the feasibility of
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5 180 blockchain in addressing the identified quality concerns, offering a fresh outlook on the issue of "rich"
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7 181 information but "poor" quality.
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10 182 **3 Methodology**

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14 183 This research adopted a multi-case strategy to assess the feasibility of blockchain in preventing handover
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16 184 information quality corrosion. Following Yin's (2018) recommendation, this research leveraged a case study
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18 185 approach for real-life insights, with comparative analysis enhancing the robustness of findings. This study
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20 186 combined semi-structured interviews and direct site observations to corroborate the participants' input. The
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22 187 investigation progressed in three phases: a narrative literature review identified frameworks and
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24 188 methodologies related to handover information management, information quality management in the AEC
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26 189 industry, and blockchain for managing construction-related information. Next, five case studies with higher
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28 190 education institutions explored the causes of the quality deterioration in handover information in the post-
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30 191 construction phase. The final phase evaluated the potential of blockchain in addressing the identified causes.
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33 192 3.1. Case Selection

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37 193 This study adopted a case-based approach for in-depth investigations in a real-world context, ideal for small
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39 194 sample sizes (Patton, 1999; Saunders *et al.*, 2019). The study strategically focuses on the higher education
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41 195 sector to derive information management strategies from its varied building functions, which can be
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43 196 applicable to a wide range of commercial buildings. Guided by Miles *et al.* (2018), this study developed the
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45 197 following selection criteria:
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- 48 198 1. Type of sector: higher education institutions,
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50 199 2. Type of physical assets: portfolios of buildings of various ages and different uses,
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52 200 3. Type of process: the use of handover information to support asset management processes.
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56 201 The appropriate number of cases for multi-case study research is a debated topic. Nonetheless, this study
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58 202 followed the widely accepted principle of theoretical saturation for determining the optimal number of cases,
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1
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3 203 as suggested by Eisenhardt (1989). This study selected cases from various countries to avoid contextual
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5 204 biases. Chosen organisations use globally recognised technological tools for managing handover information
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7 205 and adopt the International Organisation for Standardisation (ISO) 55000 standards to manage their physical
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10 206 assets. Profiles of the selected cases are detailed in Table II.

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13 207 **Table II Summary of the selected cases.**

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16 208 **3.2 Data Collection and Analysis**

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18 209 This study involved conducting semi-structured interviews with participants from each case, primarily aimed
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20 210 at gaining a comprehensive understanding of the following aspects:

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24 211 1. Organisational structure: Defining the roles and responsibilities within the Estates Division.
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26 212 2. Process: Streaming the flow of handover information pertaining to various projects.
27
28 213 3. Utilisation: The use of handover information and its quality requirements.
29
30 214 4. Management: The use of asset information management systems.

31
32 215 Table III lists 52 participants from five cases, all regular users of handover information in their job duties.
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34 216 Each interview spanned between 60 and 90 minutes. With the consent of the participants, interviews were
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37 217 recorded and transcribed to ensure accuracy and transparency. Participants received interview transcripts for
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39 218 review and verification, enhancing the study's reliability.

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42 219 **Table III Participant profiles.**

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45 220 This research adopts an inductive approach. NVivo, a qualitative data analysis software, analysed interview
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47 221 data to understand the handover information quality decline (Miles *et al.*, 2018). After thematic analysis, the
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49 222 Root Cause Analysis (RCA) technique pinpointed the root causes of quality corrosion. A comprehensive
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51 223 cross-case analysis provided further insights. These causes were then compared with blockchain technology
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53 224 characteristics to assess its potential in addressing these issues, leading to the proposition of a blockchain-
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55 225 based framework, utilising smart contracts for updating and validating handover information.

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59 226 **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 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.

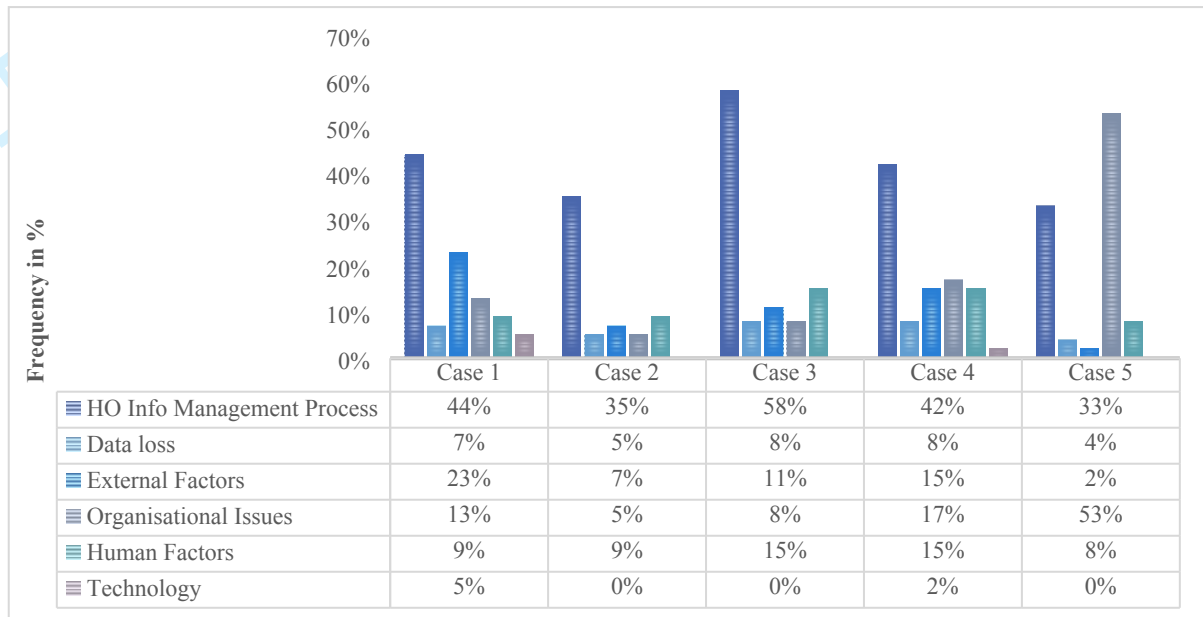


Figure 1 Comparative analysis of case studies.

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 & 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

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2
3 264 *and richness behind the CAD plans* (C2_P1). Similarly, *'when we convert 3D models into 2D plans, we lose*
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5 265 *the richness of information embedded in the 3D models. At the same time, we lose some information when*
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7 266 *converting from 2D plans to 3D models*' (C4_P2).
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11 267 Another contributing factor to information loss is the gradual erosion of the vital handover information, as
12
13 268 Yilmaz *et al.* (2015) pinpointed. Physical documents are susceptible to *'misplacement'*, *'damage'*, and
14
15 269 *'deterioration'*, further exacerbating critical information erosion over time (C1_P9, C3_P4 & C5_P2). For
16
17 270 example, older buildings tend to have less comprehensive information than newer construction. C2_P6 added,
18
19 271 *'we have fewer than 10 sheets of drawings for the 200-year-old structure, while the BIM-based projects*
20
21 272 *provide an unparalleled volume of handover information*'. This disparity is attributed to *'outdated*
22
23 273 *documentation practices*' and *'insufficient record-keeping systems*' prevalent during earlier times (C4_P9 &
24
25 274 C5_P6). Further, the mismanagement of handover information is compounded by *'the absence of*
26
27 275 *standardised procedures*' for managing such information and the inadequate implementation of information
28
29 276 migration strategies when adopting new technological solutions (C1_P18).
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32 33 277 4.1.4 External Factors

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35 278 Continuous updates in building regulations and relevant requirements often give rise to confusion and
36
37 279 inconsistencies when gathering essential handover information. This, in turn, leads to incomplete information
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39 280 and the possibility of errors (C1_P25, C2_P3, C2_P7, C4_P4 & C4_P9). For instance, the fire, life, and safety
40
41 281 systems have progressively advanced over the years (C2_P3 & C4_P8). These evolving updates create a
42
43 282 situation where asset owners lack a comprehensive understanding of the information and adequate
44
45 283 information, which hampers the quality of the handed-over information. Furthermore, the intricate nature of
46
47 284 compliance measures and reporting obligations can pose challenges in compiling accurate and complete
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49 285 information (C1_P25). These complexities can overshadow meticulous documentation practices, resulting in a
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51 286 decline in the quality of the handover information (C1_P26, C4_P4 & C5_P3).
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55 287 While effective documentation practices are instrumental in improving the quality of handover information,
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57 288 the existing AEC industry has yet to develop dedicated digital tools for managing legacy handover
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59 289 information (C1_P11, C1_P15 & C1_P18). Many buildings predating the AutoCAD era continue to rely on
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3 290 numerous physical files, outdated formats, and disorganised records for their management. These physical
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5 291 documents are prone to misplacement, damage, or even destruction, directly impacting the information's
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7 292 quality. Concurrently, legacy information collides with digitally formatted handover information (C2_P4,
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9 C3_P4 & C5_P6). As a partial solution, a platform-based approach is commonly adopted for storing and
10 293
11 exchanging file-based information, but this solution requires converting physical documents into usable
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13 formats (C4_P7). As mentioned earlier, the integrity of documents can be altered during the conversion
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15 process, limiting the future use of information.
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19 297 4.1.5 Human Errors

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21 Handover information may suffer from negative impacts due to human errors and mistakes, even those that
22 298
23 seem minor or insignificant (C1_P1, C2_P1 & C4_P1). One commonly reported error was the improper
24 299
25 distribution of handed-over information to incorrect asset information management systems or information
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27 depositories. This mistake often results in the loss of valuable information as the intended information ends up
28 301
29 in the wrong location (C1_P1, C1_P21 & C3_P3). Recurring mistakes were observed in incorrectly tagging
30 302
31 equipment and components (Yilmaz *et al.*, 2015). This led to inaccurate labelling and categorisation of items,
32 303
33 causing additional resources and time-consuming processes for verification, particularly for insurance
34 304
35 inspections. Moreover, the data entry errors in the asset information system had significant consequences. For
36 305
37 instance, incorrectly naming a building or using the wrong address resulted in information loss, inefficiencies
38 306
39 in retrieving information, and potential safety risks for occupants in emergencies.
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43 308 4.1.6 Leadership Impacts

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45
46 309 The absence of leadership support hinders the quality of handover information. This is mainly due to leaders
47
48 310 not understanding the role of handover information in the post-construction phase. Their failure to see its
49
50 311 importance makes it hard to allocate resources and implement effective strategies to improve the management
51
52 312 approach, ultimately affecting the quality. The lack of leadership support is a major obstacle to achieving
53
54 313 high-quality handover information. Without garnering support from leaders, the value and use of this
55
56 information are often overlooked, leading to mismanagement (Masood *et al.*, 2016). This misunderstanding
57 314
58 negatively impacts the efficiency after construction. Educating leaders about the crucial role of handover
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3 316 information can ensure smooth post-construction operations, as indicated by all cases (C1_P20, C2_P15,
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5 317 C4_P4, C7_P2 & C7_P3).

8 318 The comparative analysis identified six underlying reasons behind the quality decline in handover
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10 319 information, notably irregular information management processes and information loss. Additionally, the
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12 320 quality of as-built drawings was evaluated in light of technological advancement, while human errors and lack
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15 321 of leadership support contributed to the quality deterioration. However, the quality effects caused by external
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17 322 factors remain unexplored in current research. In the following section, the identified root causes are mapped
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19 323 against the characteristics of blockchain technology to explore the potential of blockchain in addressing
20
21 324 quality dilemmas.

24 325 4.2 Mapping of blockchain characteristics to root causes

27 326 Figure 2 illustrates the mapping of quality issues, blockchain features and the six core information quality
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29 327 dimensions identified in the literature (UK DAMA, 2013). The mapping exercise aims to illustrate the
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31 328 possibilities of addressing quality issues (as shown in the outer circle) correlates with the characteristics of
32
33 329 blockchain, which are represented in the middle circle of the diagram. The cross-analysis of the case study
34
35 330 revealed that inconsistent handover information management during the post-construction phase hugely
36
37 331 affects the quality of handover information. This specific cause was mapped to the corresponding blockchain
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39 332 features identified in the literature: 'single source of truth', 'transparency', 'traceability', and
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41 333 'decentralisation'. For example, defining roles and responsibilities for managing handover information can be
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43 334 enhanced by well-defined smart contracts, increasing the transparency of stakeholders' tasks and activities.
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45 335 All submitted documents will be recorded in an immutable manner, enabling to trace the information as long
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47 336 as the blockchain exists. Moreover, the decentralised concept of managing documents removes one
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49
50 337 controlling party revising the documents. Combining these attributes will achieve a 'single source of truth' for
51
52 338 asset information to support the future use of buildings.

55 339 Subsequently, the blockchain features are connected to the relevant information quality attributes of
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57 340 information quality in the handover information, which is displayed in the central circle of the figure. For
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59 341 example, completeness of information would be ensured by providing a blockchain-based historical record of

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3 342 all transactions and by incorporating smart contracts to detect incomplete information. Blockchain ensures
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5 343 uniqueness as it provides a single source of truth for all participating nodes. Keeping track of all versions of
6
7 344 the files and their metadata provides data timeliness, accuracy, and validity, which is strengthened even more
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9
10 345 by the immutability of blockchain records. The consistency of data records is ensured by smart contracts
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12 346 validating if the information is classified correctly.

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15 347 In the mapping exercise, leadership impact was not mapped to any characteristics of blockchain. The
16
17 348 leadership impact caused by the quality deterioration of handover information is not an isolated cause, but
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19 349 support from leadership is necessary to realise the full benefits of implementing blockchain technology to
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21 350 prevent the quality decline. Features like 'anonymity' and 'protection of IP rights' were also not mapped
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23 351 because these features are irrelevant to the handover information management. This exercise culminated in a
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25 352 proposed conceptual framework for managing handover information irrespective of project size as the asset
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27 353 owners update different assets.

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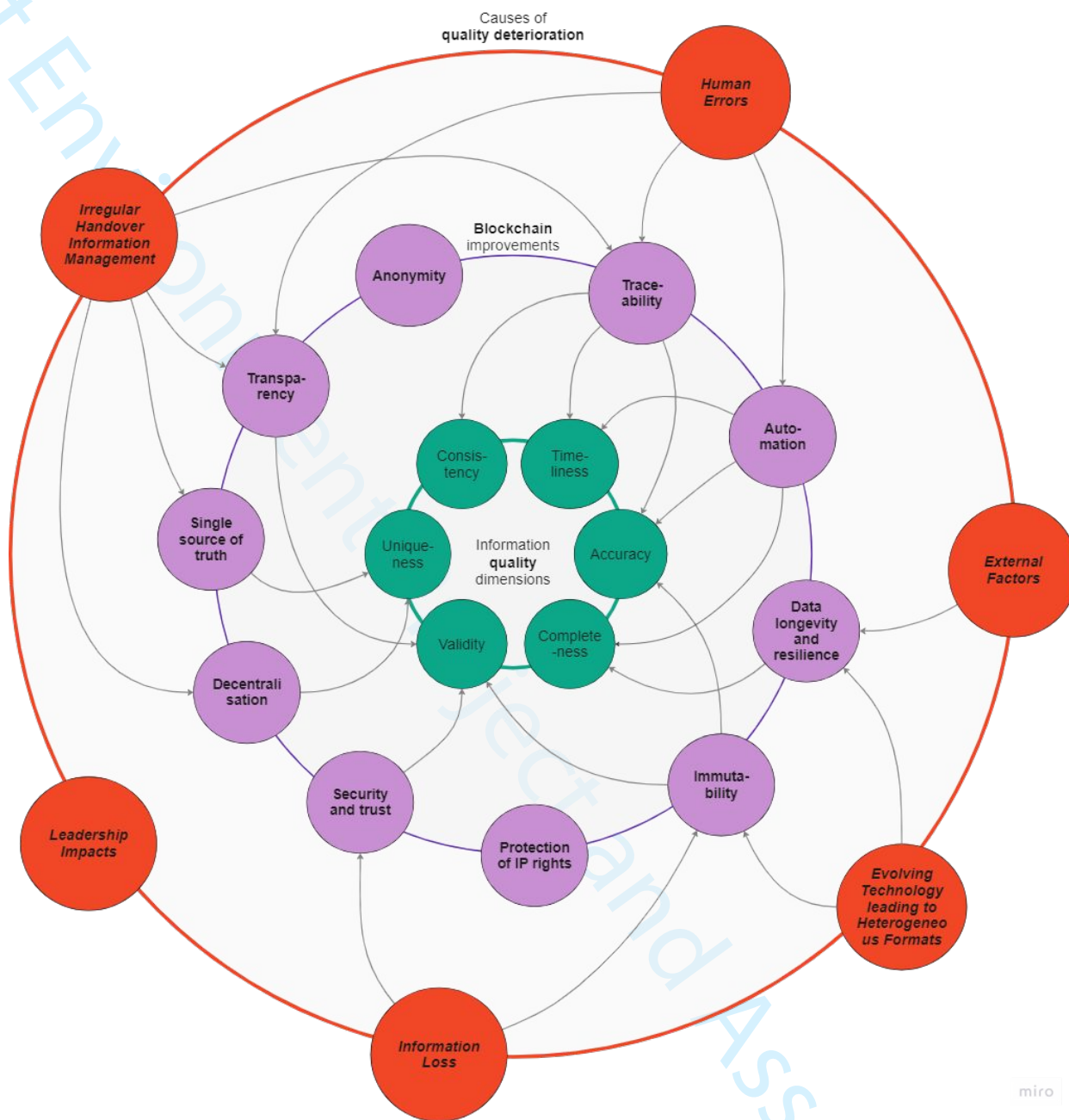


Figure 2. Mapping of root causes, blockchain attributes and data quality dimensions.

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.

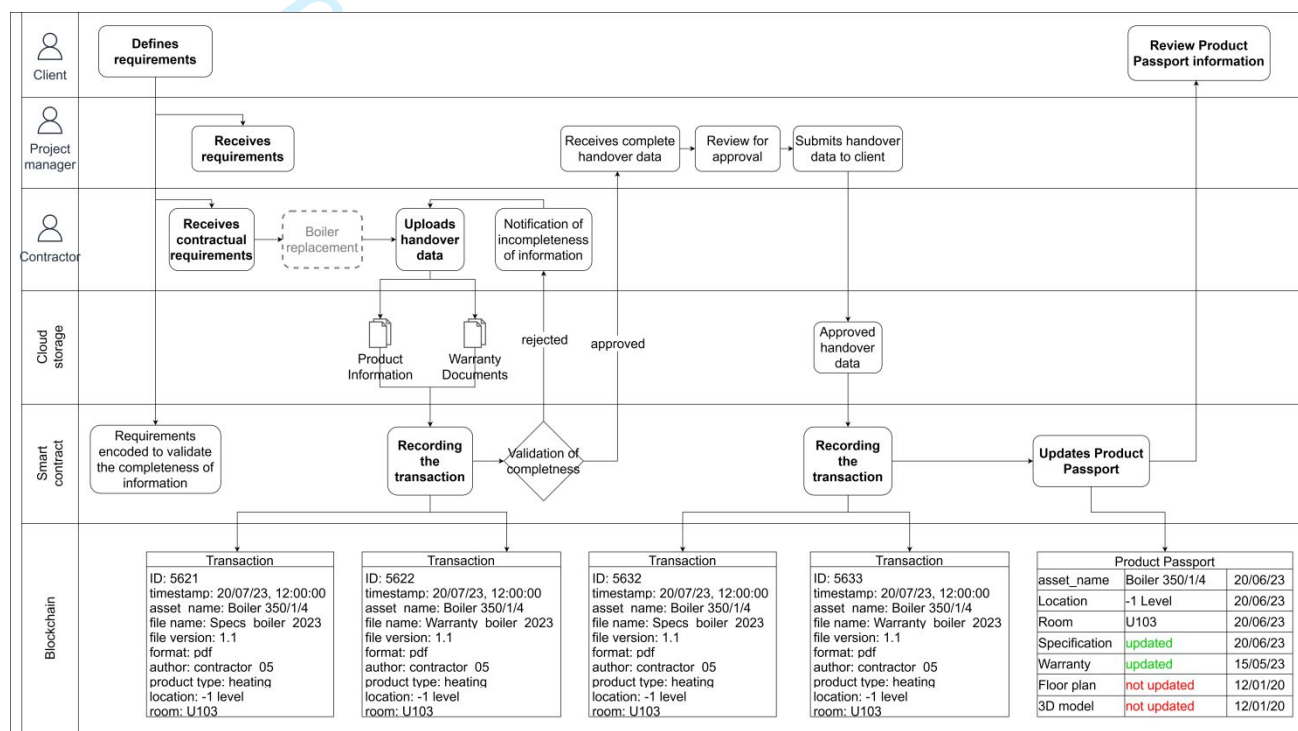


Figure 3. A conceptual blockchain framework of handover information collection process.

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,

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3 377 which limits updating in the product passport. Therefore, the client will observe that the drawings or 3D
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5 378 models related to the replacement units are missing from the product passport review.
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8 379 **5 Discussion**

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11 380 The investigation into handover information management reveals that robust information management is
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13 381 pivotal to maintaining the integrity and quality of information. These findings align with Masood *et al.*
14
15 382 (2016), who underscores the critical role of uniform information management processes in ensuring the long-
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17 383 term quality of information. Further compounding these issues, Yilmaz *et al.* (2015) pinpoint the tangible
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19 384 risks associated with physical information loss and the adverse effects of outdated and ineffective record-
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21 385 keeping methods on the quality of handover information.
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25 386 Transitioning to the broader context, information is constantly evolving through major and minor projects,
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27 387 ranging from extensive renovations to equipment replacements. Each project represents a transactional update
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29 388 event, where accuracy is critical to prevent cascading issues. Love *et al.* (2018) stress the importance of
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31 389 precision in maintaining as-built drawings. Despite the critical nature of managing transactional updates, the
32
33 390 task of updating graphical information and corresponding non-graphical information remains vulnerable,
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35 391 mainly due to its reliance on manual updates. This vulnerability stems from the ingrained nature of asset
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37 392 information management in current workflows. Further, there is a notable knowledge gap concerning the
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39 393 effects of poor legacy information management and the assimilation of evolving regulatory demands on the
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41 394 quality of information. This indicates underlying systemic issues in information governance, extending
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43 395 beyond technological solutions.
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47 396 Viewed through this transactional lens, blockchain emerges as a potential, though not originally developed as
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49 397 an information management tool. Blockchain addresses specific concerns, such as immutability and
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51 398 decentralisation, which are highly relevant to asset information management. While blockchain cannot create
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53 399 new information or rectify digitalisation errors, it offers a reliable mechanism for tracking the provenance and
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55 400 changes made to asset information. over time, this could lead to the creation of more reliable information.
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57 401 Furthermore, blockchain's immutable nature ensures that every transaction is recorded with the necessary
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3 402 quality for managing the long lifespan of buildings. The adoption of Distributed Ledger Technology (DLT)
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5 403 like blockchain could markedly improve the efficiency in the detailed documentation and tracking of updates
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7 404 with foundational trust in business relationships, especially in the AEC industry (Qian and Papdonikolaki,
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9 405 2020).

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13 406 It is noteworthy to state that blockchain's security feature is significant, yet this study indicates asset
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15 407 management professionals, especially in higher education, may underemphasise security concerns. Parn and
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17 408 Edwards (2019) stressed the need to harness blockchain's security for protecting assets in high-risk
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19 409 environments, such as banks, prisons, and defence facilities. Although resilient, blockchain is not impervious
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21 410 to threats. Yli-Huumo *et al.* (2016) raised a cautionary note about vulnerabilities, such as the '51% attack',
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23 411 where control over half of the network could lead to blockchain manipulation. This risk illuminates the
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25 412 necessity for vigilant management and robust strategies when implementing blockchain technology.

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28 413 In sum, it is critical to weigh blockchain's benefits against its limitations and consider its function in an
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30 414 extensive operational context. Key aspects include fostering trust and developing an integrated strategy to
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32 415 handle assets' amassed digital and physical information. Utilising blockchain to enhance transactional and
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34 416 provenance tracking in asset management can significantly improve information quality.

35 36 37 38 417 **6 Conclusions**

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41 418 This research's evidence-based case study approach identified the root causes of handover information quality
42
43 419 deterioration based on multiple cases. A blockchain-based framework was then proposed to improve the
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45 420 management of handover information, aligning the identified root causes with blockchain features and
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47 421 information quality dimensions. This approach, not presented in previous studies, highlights the unique
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49 422 challenges and limitations of implementing blockchain technology in the management of asset information,
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51 423 including building handover information.

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54 424 This study offers theoretical and practical contributions. On a theoretical level, it positions blockchain
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56 425 technology as a potentially disruptive innovation yet acknowledges its limitations in fully addressing the
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3 426 complexities of handover information management. It challenges the assumption that blockchain can entirely
4
5 427 overhaul existing information flows and associated processes in the cases studied.
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8 428 Practically, the study provides managers and practitioners with a framework to improve the quality of the
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10 429 handover information management process using blockchain technology. The study highlights the need for
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12 430 organisations to tailor blockchain solutions to their specific needs, ensuring effective enhancement of the
13
14 431 information quality. The research underscores the importance of bespoke strategies in integrating blockchain
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16 432 technology to prevent quality deterioration in handover information, illuminating the practical implications.
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20 433 Building on vital insights from asset management professionals, this study proposes a conceptual framework
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22 434 for managing handover information. However, this study poses certain limitations. Its scope is narrowly
23
24 435 confined to information management in asset management, excluding a facilities management perspective. A
25
26 436 notable challenge identified is the extensive outsourcing of facilities management tasks in the participating
27
28 437 organisations, a trend noted by Adhikari *et al.* (2019). Consequently, future research is essential to evaluate
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30 438 blockchain's productivity and cost-benefits for developing a refined prototype or proof of concept. Such
31
32 439 research is crucial for a broader scale, including by third-party service contractors accessing and updating
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34 440 asset information.
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37 38 441 **7 Acknowledgement**

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41 442 This work was supported by the XXXXX-XXXXX XXXXXXXXXXX XXXXXXXXXXXXXXX XXXXXXXXXXX
42
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44
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1 Can Blockchain Prevent the Deterioration of ~~Building Building~~ Handover Information Quality 2 for Higher Education Institutions? 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

4 Abstract

5 **Purpose** – This research investigates the distinct characteristics of blockchain technology to safeguard against
6 the deterioration of handover information quality in the post-construction phase. The significance of effective
7 management of handover information is highlighted by global building failures, such as the Grenfell Tower
8 fire in London, UK. Despite existing technological interventions, there remains a paucity of understanding
9 regarding the factors contributing to the decline in the quality of handover information during the post-
10 construction phase. The significance of effective management of building handover information has been
11 underscored by numerous building failures worldwide. Despite the implementation of technological solutions,
12 limited knowledge is available to understand the underlying reasons contributing to the decline in the quality
13 of handover information during the post-construction phase. This research examines the distinct
14 characteristics of blockchain technology that can potentially prevent the quality deterioration of handover
15 information during the post-construction phase.

16 **Design/methodology/approach** – This study employed a multi-case studies approach across five higher
17 education institutions. It involved conducting semi-structured interviews with 52 asset management
18 professionals, uncovering the underlying reasons for the decline in handover information quality. Building on
19 these insights, the study performed a mapping exercise to align these identified factors with blockchain
20 technology features and information quality dimensions, aiming to evaluate blockchain's potential in
21 managing quality handover information. This study employed a two-step approach. Initially, we conducted
22 five case studies involving higher education institutions and interviewed 52 asset management professionals to
23 identify the underlying factors contributing to the decline in the quality of handover information.
24 Subsequently, we performed a mapping exercise to correlate the identified root causes of quality decline with
25 the features of blockchain and information quality dimensions. This exercise evaluated the potential of
26 blockchain in preventing quality deterioration of the identified causes.

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3 27 **Findings** – The study findings suggest that blockchain technology offers advantages but has limitations in
4
5 28 addressing all the identified quality issues of managing handover information. Due to the lack of an automated
6
7 29 process and file-based information exchange, updating handover information still requires an error-prone
8
9 30 manual process, leading to potential information loss. Additionally, no solutions are available for encoding
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11 31 drawings for updates and validation.

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14 32 **Originality/value** – This study proposes a framework integrating blockchain to enhance the information
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16 33 management process and improve handover information quality.

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20 34 **KEYWORDS:** Handover Information, Information Quality, Asset Information Management, Blockchain
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22 35 Technology, Higher Education Institutions

23 24 25 36 **1 Introduction**

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28 37 ~~Inadequate Poor-quality~~ information can introduce significant organisational inefficiencies, culminating in
29
30 38 major financial challenges. Batini and Scannapieco (2016) highlight the severe financial repercussions of poor
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32 39 information quality. They point to the 2002 Data Warehousing Institute report, which revealed that US
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34 40 businesses suffered an annual loss exceeding \$600 billion due to inferior information quality (Eckerson,
35
36 41 2002). Similarly, the Architecture, Engineering and Construction (AEC) industry is not immune to these
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38 42 losses. Matarneh *et al.* (2019) highlighted that poor asset information management in the post-construction
39
40 43 phase leads to an estimated annual loss of \$10 billion in the US building industry. Moreover, recent building
41
42 44 failures linked to ~~insufficient inadequate~~ handover information management pose financial risks and further
43
44 45 compromise the safety of occupants (Hackitt, 2017).

46
47
48 46 Handover information (HO) is the primary asset information source for the management of buildings
49
50 47 (Pinheiro, 2019). ~~Provided upon project completion, Initially this information starts as static, this information~~
51
52 48 ~~but evolves dynamically in response to change throughout the building's lifecycle, requiring an effective~~
53
54 49 ~~information management solution becomes dynamic as buildings undergo changes~~ (Leygonie, 2020).
55
56 50 ~~Investigations into various building failures have exposed the detrimental consequences of pervasive~~
57
58 51 ~~deficiencies in current building information management practices, leading to inaccurate, incomplete, and~~
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1
2
3 52 outdated information, which poses serious safety consequences (Hackitt, 2018; UK, 2022). Building
4
5 53 Information Modelling (BIM) holds the potential to augment handover information quality. However, its
6
7 54 application is predominately in new construction, which constitutes about only 1 to 2 per cent of the total
8
9 55 building stock annually (Roberts *et al.*, 2018). Consequently, BIM's information management capacity often
10
11 56 bypasses pre-digital era constructions reliant on legacy information, which lacks transparency and
12
13 57 accountability, especially in the verification of updates by stakeholders. With approximately 85% of the
14
15 58 buildings in the European Union predating BIM, the importance of effective information management is
16
17 59 significantly heightened (European Commission, 2020). This situation illuminates the urgency of addressing
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19 60 existing shortcomings in practices, particularly emphasising the vital importance of trustworthy handover
20
21 61 information. Credible and valid handover information is vital for future use of buildings. As a result, it is in
22
23 62 the asset owners' best interest to manage quality handover information, especially considering that roughly
24
25 63 85% of a building's total investment occurs during the post-construction phase (Chang *et al.*, 2022a; Thabet
26
27 64 and Lucas, 2017). Despite its significance, many studies highlight shortcomings in handover information
28
29 65 management, suggesting that compromised quality leads to potentially costly errors. Yet, limited knowledge
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31 66 is available to understand the reasons behind the quality deterioration of handover information.

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36 67 Blockchain technology, recognised for its potential to uphold the quality of handover information, offers a
37
38 68 promising avenue for streamlining information exchange across various disciplines in a building project
39
40 69 (Nawari and Ravindran, 2019). Blockchain is a decentralised ledger that records and shares every transaction
41
42 70 within the network among its participants (Mukherjee and Pradhan, 2021) (Nawari and Ravindran, 2019).
43
44 71 Blockchain has the potential to address prevalent issues in handover processes, such as insufficient record-
45
46 72 keeping, inadequate paperwork furnished by contractors, and challenges in accessing information
47
48 73 information (Ali *et al.*, 2020). Its capacity to provide audit trails illuminates transparency and accountability
49
50 74 (Mahmudnia *et al.*, 2022). Blockchain's transparency ensures a clear understanding of the ledger's status,
51
52 75 enhancing participant accountability, while its traceability feature allows for the verification of information
53
54 76 with accurate timestamps (Kshetri, 2017; Montecchi *et al.*, 2019). Offering a secure, uniform, and transparent
55
56 77 approach, blockchain stands out as a suitable alternative to traditional centralised systems, improving the
57
58 78 quality of the information (Love *et al.*, 2005).
59
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Parn et al. (2016) have highlighted the potential of Building Information Modelling (BIM) to manage reliable information throughout a building's lifecycle. However, this view is contested by several researchers who argue that BIM alone is an insufficient solution for managing the essential information (Hijazi et al., 2021; Olatunji and Akanmu, 2015). One significant limitation in the current implementation of BIM is the practice of exchanging information through file-based information. This approach has been shown to reduce the effectiveness of BIM in the operations (Wilkinson et al., 2016). Furthermore, more attention should be directed to improving the approach of people and processes in client organisations (Bosch et al., 2015). The lack of stakeholder engagement has been identified as contributing to issues with information traceability and trust (Hijazi et al., 2022). Shemov et al. (2020) have further expanded that the erosion of trust leads to issues with transparency. Despite its capabilities, information quality in BIM is often plagued by mismanagement of information, lack of consistent information requirements, and an absence of reliability and trust (Salinas and Prado, 2019). BIM's project-specific asset information management approach also limits overseeing portfolios-based building management with quality information (Fang et al., 2022). In light of these challenges, our research seeks to explore the application of blockchain technology as a means to prevent the quality decline in handover information. By evaluating the principles-features of blockchain in this context uncovers we aim to identify opportunities for innovation and improvement in information management within the commercial building-higher education sector, posing -

Therefore, we pose the following research question:

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

To answer this question, we adopt This study adopts a multi-case study approach, investigating involving the higher education institutions sector across the UK, Ireland, Germany, and Northern Ireland. This focus is motivated by prior research, which has underscoring asset management ed the inefficiencies in asset management, largely attributable to inferior asset information quality within higher education institutions 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. For data collection, we conducted semi-structured interviews with asset management professionals who use handover information regularly. To corroborate their insights, we conducted onsite observations. Following an in-depth analysis of the interviews, we evaluated the potential of blockchain technology to address the identified issues causing the decline in information quality. Unlike previous studies on the blockchain, our approach begins by identifying the root causes of the problem before assessing the applicability of blockchain features. By taking this empirical evidence-based approach, we aim to offer a solution capable of preventing further deterioration in the quality of handover information.

~~The remainder of~~ this research is organised as follows. Section 2 reviews the literature studies on handover information in building management, information quality dimensions and characteristics of blockchain technology. Section 3 outlines the methodology for evaluating used to assess the potential of blockchain to prevent ~~t-information quality deterioration based quality on the evidence decline.~~ Section 4 ~~introduces proposes~~ a blockchain information management framework, addressing work thefor managing handover information using blockchain based on identified root causes of information deterioration causes. Section 5 ~~evaluates the pros and cons~~ discusses a critical analysis of the findings. ~~of managing different types of handover information.~~ Section 6 offers ~~a critical analysis of the findings~~ 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 ~~building handover information~~ 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, ~~5 focusing on managing handover information and the root causes of the quality decline of such information during the post-construction phase.~~ This study follows the DIKW-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 ~~information includes critical details in three~~ includes three information types formats: 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). ~~On the other hand,~~ non-graphical and documentation offer supplementary details, ~~such as including~~ operation & 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 ²-specific information requirements ~~commonly dictate the categories of handover information to be complied~~ (BSI, 2013). Accordingly, contractors involved with a building project provide the required ~~handover~~ information during in the handover phase (Zhu *et al.*, 2021).

Handover information is pivotal 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). ~~It guides regular maintenance and operational support, ensuring the building's proper functioning and longevity (Chang et al., 2022).~~ 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). ~~It also plays a k~~ This information also significantly impacts role in building energy simulations,

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2
3 157 improving energy efficiency and achieving sustainable development goals (Pinheiro, 2019). However, ~~poor~~
4
5 158 ~~management of handover information has led to building failures, making it not just beneficial but mandatory~~
6
7 159 ~~for safety (Hackett, 2017, 2018).~~ Despite its importance, there is limited understanding of why the quality of
8
9
10 160 handover information deteriorates.

11 12 13 161 2.2 The definition of information, its characteristics and information quality dimensions

14
15 162 The effective management of handover information demands ~~a clear~~ understanding ~~of the its~~ nature ~~of~~
16
17 163 ~~information~~, management perspective and quality standards. Information is processed data, ~~while it~~ can be
18
19 164 repurposed without losing value ~~yet may, it can~~ become outdated (Batini and Scannapieco, 2016; Mingers,
20
21 165 1996). Information management involves creating, acquiring, organising, storing, disseminating, and using
22
23 166 information. Correspondingly, Wang *et al.* (1998) advise treating information like a manufactured product:
24
25
26 167 recognising the specific needs of the information, managing the information as a product, overseeing the
27
28 168 information throughout its lifecycle, and appointing dedicated roles to administer information. Concepts from
29
30 169 manufacturing ~~Various~~ quality management ~~concepts from manufacturing~~ can ~~assess~~ ~~be utilised to evaluate~~
31
32 170 ~~the~~ required quality attributes (Borek, 2012).

33
34
35 171 Quality information is commonly defined as information ~~to satisfy~~ ing user ~~the~~ requirements, ~~of information~~
36
37 172 ~~users that can be~~ categorised into four types (English, 1999; Wang and Strong, 1996). Wang and Strong
38
39 173 (1996) proposed four categories of information quality: intrinsic, contextual, representational and accessibility
40
41 174 data quality. Intrinsic quality focuses on accuracy and credibility, while contextual quality emphasises
42
43 175 relevance and timeliness. Representational quality deals with ease of understanding, and accessibility quality
44
45 176 concerns secure and easy access. English (1999) further classified the characteristics of dimensions into two
46
47
48 177 broad categories: (1) Inherent information quality and (2) Pragmatic information quality. Inherent quality
49
50 178 refers to data that can stand alone, such as 'accuracy' and 'non-duplication'. Pragmatic quality focuses on
51
52 179 meeting end-user needs, including 'accessibility' and 'usability'.

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55 180 Combining the English and ~~Wang~~ Wang and Strong's approaches, the Data Management (DAMA) UK
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57 181 Working Group - UK DAMA (2013) published six core quality dimensions, including the definitions and the
58
59 182 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:

- Completeness: All required data are present to meet the user's requirements
- Uniqueness: No data is recorded more than once
- Timeliness: All required data are sufficiently updated for the task
- Validity: All data conform to the syntax (e.g., format, type, etc.) within its definition
- Accuracy: Data correctly represent the actual value
- 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 ~~Implementing blockchain technology in~~ the Architecture, Engineering and Construction (AEC) industry, blockchain technology has emerged as a noteworthy candidate for the management of information quality. ~~has been a topic of numerous publications in recent years.~~

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) ~~(Mukherjee and Pradhan, 2021b). We reviewed several papers adopting systematic literature review to investigate the benefits and limitations of blockchain technology, particularly in managing credible handover information during the post-construction phase (Hijazi *et al.*, 2021; Li and Kassem, 2021; Penzes, 2018; Perera *et al.*, 2020). For a succinct overview, >>Table I summarises the salient features of blockchain relevant to information management, complemented by 's most beneficial characteristics in managing handover information, followed 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; streamlines supply chain management by serving as~~ a single reliable source of information for all stakeholders by storing identical records across nodes to enhance the credibility of the information (Hijazi *et*

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2
3 208 *al.*, 2021). ~~This technology stores identical records across nodes, enhancing the credibility of the information~~
4
5 209 ~~(Perera *et al.*, 2020). Unlike cloud computing,~~ the decentralised nature of blockchain eliminates single
6
7 210 points of failure, ~~enhancing~~ improving resilience and data integrity (Perera *et al.*, 2020). It also facilitates
8
9
10 211 better data exchange, contributing to sustainability by ensuring transparent material and data origins (Shojaei
11
12 212 *et al.*, 2019). Blockchain-based Material and Product Passports provide a trustworthy information source
13
14 213 throughout the whole lifecycle of a built asset (Li and Wang, 2021). Security is another strong suit: data
15
16 214 manipulation is nearly impossible as changes must be made across all nodes and blocks-(Mukherjee and
17
18 215 Pradhan, 2021)(Mukherjee and Pradhan, 2021b). The technology employs consensus mechanisms and public-
19
20 216 key cryptography to maintain data integrity and privacy (Perera *et al.*, 2020). One of the most fundamental
21
22 217 features is smart contracts, self-executing codes that operate without intermediaries once set conditions are
23
24 218 fulfilled- (Mukherjee and Pradhan, 2021)(Mukherjee and Pradhan, 2021b). These contracts foster trust among
25
26 219 stakeholders (Kim *et al.*, 2020). However, there have yet to be validation studies that confirm the acclaimed
27
28 220 benefits of blockchain technology in managing asset information, including handover information (Wang *et*
29
30
31 221 *al.* 2017).

32
33
34 222 **>>Table I Principles of blockchain.**

35 223 36 37 224 2.4 Applications of blockchain in the AEC industry

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39
40 225 Several studies showcase the applications of blockchain's versatility, particularly its problem-solving
41
42 226 capabilities rooted in payment systems, collaboration and documentation, throughout various stages of a
43
44 227 building's lifecycle (Li and Kassem, 2021; Mahmudnia *et al.*, 2022). In the design phase, the blockchain's
45
46 228 immutable record-keeping feature tracks all design changes, streamlining the design collaborative
47
48 229 coordination process to minimise ambiguities in design documents (Di Giuda *et al.*, 2020). Moreover,
49
50 230 blockchain applications extend to improving supply chain management and progress payments in construction
51
52 231 to avoid construction delays (Ahmadisheykhsarmast and Sonmez, 2020; Qian and Papadonikolaki, 2020).
53
54 232 Beyond construction, Götz *et al.* (2020) advocate leveraging blockchain for documenting post-construction
55
56 233 operational data and information, ensuring the preservation of essential information for future use and
57
58 234 complying with the legal duties of operating buildings (Li *et al.*, 2019).
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2.42.5 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 ~~implementing~~ blockchain ~~principles~~ in preventing ~~the causes of~~ handover information quality corrosion. ~~According to~~ ~~Following~~ Yin's (2018) ~~recommendation~~, ~~this research leveraged~~ a case study approach ~~is well-suited for capturing insights from~~ ~~for~~ real-life ~~situations~~ ~~insights~~, ~~with~~, ~~and~~ comparative analysis ~~enhancing the robustness of findings~~. ~~of multiple case studies provides conclusive and convincing evidence~~. This study ~~employed combined semi-structured interviews and direct site observations as its data sources~~. (Yin, 2018) ~~and direct site observations to corroborate the participants' input~~. ~~While semi-structured interviews were used as the main method, direct site observations further corroborated the participants' input~~. ~~The investigation progressed in three phases:~~

~~This study involves three distinctive phases. Firstly, we conducted~~ a narrative literature review ~~identified to~~ ~~identify~~ frameworks and methodologies ~~used in previous studies~~ related to handover information management, information quality management in the AEC industry, and ~~the use of~~ blockchain ~~for in~~ managing construction-related information. Next, ~~we conducted~~ five case studies with higher education institutions ~~in the UK, Northern Ireland, Germany, and Ireland explored to identify the underlying reasons~~ ~~causes of~~ ~~for~~ the quality deterioration in handover information ~~during in~~ the post-construction phase.

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2
3 260 ~~Successively, The final phase evaluated two assessed the feasibility potential~~ of blockchain technology in
4
5 261 addressing the identified causes, ~~that contribute to the deterioration of handover information quality.~~

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11 263 ~~3.1~~ 3.1. Case Selection

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15 264 ~~For this study, This study adopted we argue that~~ a case-based approach is suitable for conducting in-depth
16
17 265 investigations ~~within in a the~~ real-world context, ~~especially when ideal for addressing the research questions~~
18
19 266 ~~based on the~~ small sample sizes (Patton, 1999; Saunders *et al.*, 2019). ~~The study strategically focuses on the~~
20
21 267 ~~higher education sector to derive information management strategies from its varied building functions, which~~
22
23 268 ~~can be applicable to a wide range of commercial buildings.~~ -Guided by Miles *et al.* (2018), ~~this study~~
24
25 269 ~~developed we identified five cases based on~~ the following selection criteria:

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27
28 270 1. Type of sector: higher education institutions,
29
30 271 2. Type of physical assets: portfolios of buildings of various ages and different uses,
31
32 272 3. Type of process: the use of handover information to support asset management processes.
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35
36 273 The appropriate number of cases for multi-case study research is a debated topic. Nonetheless, ~~we~~
37
38 274 ~~followed this study followed~~ the widely accepted principle of theoretical saturation ~~to determine for~~
39
40 275 ~~determining~~ the optimal number of cases, as suggested by Eisenhardt (1989). This study selected cases from
41
42 276 various countries to avoid contextual biases. Chosen organisations use globally recognised technological
43
44 277 tools for managing handover information and adopt ~~the International Organisation for Standardisation (ISO)~~
45
46 278 ~~ISO-55000~~ standards to manage their physical assets. Profiles of the selected cases are detailed in Table II.
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49 279 ~~>>~~ **Table II Summary of the selected cases.**

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51
52 280 3.2 Data Collection and Analysis

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54
55 281 ~~Our This~~ study involved conducting semi-structured interviews with participants ~~to gather suitable data~~ from
56
57 282 each case, ~~primarily aimed at gaining.~~ ~~The primary objectives of the interviews were to gain~~ a comprehensive
58
59 283 understanding of the following aspects:
60

1. Organisational structure~~Structure~~: Defining the roles and responsibilities within the Estates Division~~The structure of the estates' division with the roles and responsibilities of the different groups involved.~~
2. Process~~The process of streaming varieties of the flow of~~ handover information pertaining to various projects~~.~~
3. Utilisation: The use of handover information and its quality requirements~~.~~
4. The management of handover information~~Management: T, including~~ the use of asset information management systems.

Table III lists 52 participants from five cases, all regular users of ~~involved in the study.~~ These participants regularly use handover information in ~~to perform~~ their job duties. Each interview spanned between 60 and 90 minutes. With the consent of the participants, interviews were recorded and transcribed to ensure accuracy and transparency. Further, we ensured the reliability of the study ~~Participants received interview transcripts for review and verification, enhancing the study's reliability. by sending each participant a copy of the interview transcript, allowing them to review and verify the accuracy of their input.~~

>>Table III Participant profiles.

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

4 Findings

4.1 The Results of Comparative Analysis

This section provides ~~six the~~ root causes of the handover information quality deterioration across five cases, ~~determined through thematic analysis. Utilising thematic analysis, together with a cause-and-effect diagram,~~ ~~the root causes are classified into six categories:~~ (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~~ was also created based on the occurrences of the reported issues from each case. The purpose ~~of creating 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). (Masood et al., 2016) EE~~ Each case ~~identified~~ ~~reported that the~~ two primary sources of handover information: ~~are~~ 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 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.

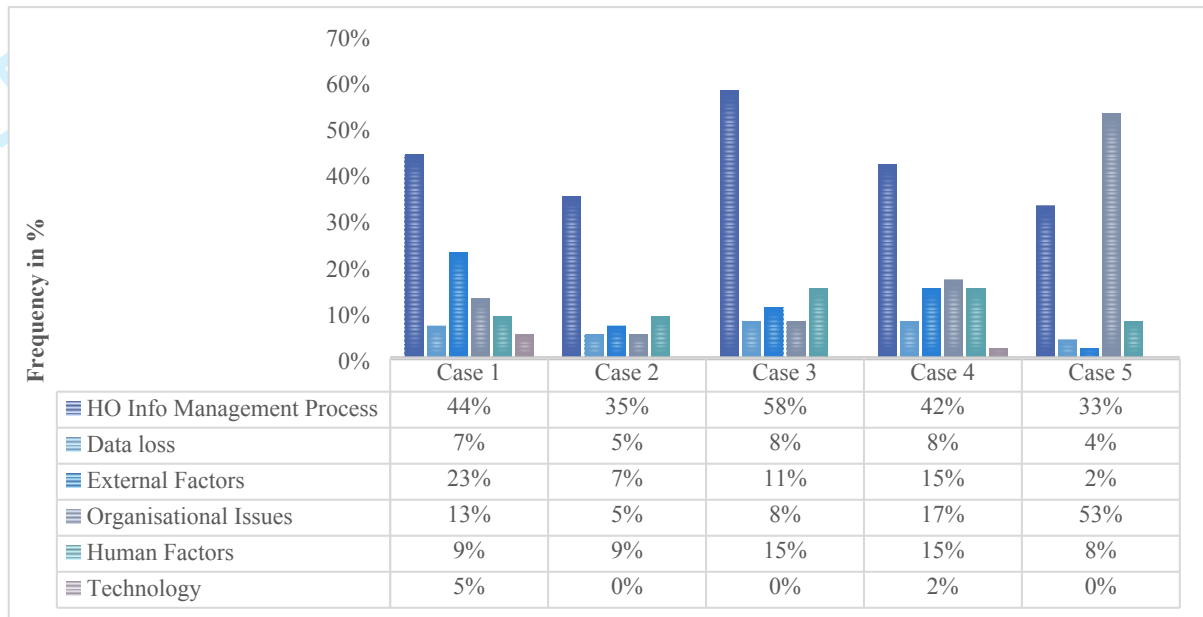


Figure 1 Comparative analysis of case studies.

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). Especially the recent adoption of BIM has introduced additional non-conventional formats, particularly for the drawings such as 3-dimensional models and IFC files. Consequently, 'we have varieties of as-built formats, including hard copies, including 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 & 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

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2
3 347 *and richness behind the CAD plans*' (C2_P1). Similarly, *'when we convert 3D models into 2D plans, we lose*
4
5 348 *the richness of information embedded in the 3D models. At the same time, we lose some information when*
6
7 349 *converting from 2D plans to 3D models*' (C4_P2).
8
9

10 350 Another contributing factor to information loss is the gradual erosion of the vital handover information, as
11
12 351 (Yilmaz, G et al. (2015) pinpointed, -Physical documents are susceptible to 'misplacement', 'damage', and
13
14
15 352 *'deterioration', further exacerbating critical information erosion over time (C1_P9, C3_P4 & C5_P2). For*
16
17 353 *example, older buildings tend to have less comprehensive information than newer construction. C2_P6 added,*
18
19 354 *' we have fewer than 10 sheets of drawings for the 200-year-old structure, while the BIM-based projects*
20
21 355 *provide an unparalleled volume of handover information*'. This disparity is attributed to *'outdated*
22
23 356 *documentation practices*' and *'insufficient record-keeping systems*' prevalent during earlier times (C4_P9 &
24
25 357 C5_P6). Further, the mismanagement of handover information is compounded by *'the absence of*
26
27 358 *standardised procedures*' for managing such information and the inadequate implementation of information
28
29 359 *migration strategies when adopting new technological solutions (C1_P18).*
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31

32 360 4.1.4 External Factors

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35 361 Continuous updates in building regulations and relevant requirements often give rise to confusion and
36
37 362 inconsistencies when gathering essential handover information. This, in turn, leads to incomplete information
38
39 363 and the possibility of errors (C1_P25, C2_P3, C2_P7, C4_P4 & C4_P9). For instance, the fire, life, and safety
40
41 364 systems have progressively advanced over the years (C2_P3 & C4_P8). These evolving updates create a
42
43 365 situation where asset owners lack a comprehensive understanding of the information and adequate
44
45 366 information, which hampers the quality of the handed-over information. Furthermore, the intricate nature of
46
47 367 compliance measures and reporting obligations can pose challenges in compiling accurate and complete
48
49 368 information (C1_P25). These complexities can overshadow meticulous documentation practices, resulting in a
50
51 369 decline in the quality of the handover information (C1_P26, C4_P4 & C5_P3).
52
53
54

55 370 While effective documentation practices are instrumental in improving the quality of handover information,
56
57 371 the existing AEC industry has yet to develop dedicated digital tools for managing legacy handover
58
59 372 information (C1_P11, C1_P15 & C1_P18). Many buildings predating the AutoCAD era continue to rely on
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1
2
3 373 numerous physical files, outdated formats, and disorganised records for their management. These physical
4
5 374 documents are prone to misplacement, damage, or even destruction, directly impacting the information's
6
7 375 quality. Concurrently, legacy information collides with digitally formatted handover information (C2_P4,
8
9
10 376 C3_P4 & C5_P6). As a partial solution, a platform-based approach is commonly adopted for storing and
11
12 377 exchanging file-based information, but this solution requires converting physical documents into usable
13
14 378 formats (C4_P7). As mentioned earlier, the integrity of documents can be altered during the conversion
15
16 379 process, limiting the future use of information.

17 18 19 380 4.1.5 Human Errors

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21
22 381 Handover information may suffer from negative impacts due to human errors and mistakes, even those that
23
24 382 seem minor or insignificant (C1_P1, C2_P1 & C4_P1). One commonly reported error was the improper
25
26 383 distribution of handed-over information to incorrect asset information management systems or information
27
28 384 depositories. This mistake often results in the loss of valuable information as the intended information ends up
29
30 385 in the wrong location (C1_P1, C1_P21 & C3_P3). ~~Additionally,~~ recurring mistakes were observed in
31
32 386 incorrectly tagging equipment and components (Yilmaz *et al.*, 2015). This led to inaccurate labelling and
33
34 387 categorisation of items, causing additional resources and time-consuming processes for verification,
35
36 388 particularly for insurance inspections. Moreover, the data entry errors in the asset information system had
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38 389 significant consequences. For instance, incorrectly naming a building or using the wrong address resulted in
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40 390 information loss, inefficiencies in retrieving information, and potential safety risks for occupants in
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43 391 emergencies.

44 45 46 392 4.1.6 Leadership Impacts

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48 393 The absence of leadership support hinders the quality of handover information. This is mainly due to leaders
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50 394 not understanding the role of handover information in the post-construction phase. Their failure to see its
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52 395 importance makes it hard to allocate resources and implement effective strategies to improve the management
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55 396 approach, ultimately affecting the quality. The lack of leadership support is a major obstacle to achieving
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57 397 high-quality handover information. Without garnering support from leaders, the value and use of this
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59 398 information are often overlooked, leading to mismanagement (Masood *et al.*, 2016). This misunderstanding
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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 & C7_P3).

The ~~results of 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. n—In the following section, ~~we mapped~~ the identified root causes are mapped against ~~and~~ the characteristics of blockchain technology to delve into ~~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 purpose of the~~ mapping exercise aims ~~is~~ to ~~demonstrate~~ 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. by leveraging blockchain technology.—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 ~~Accordingly, we mapped this particular cause to appropriate~~ blockchain features based on the definition provided in the ~~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, increasing the transparency of stakeholders’ tasks and activities. All submitted documents will be recorded in an immutable manner, enabling to trace the information; ~~therefore, they can be traced for~~ 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.

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3 425 Subsequently, ~~we connect~~ the blockchain features are connected to the relevant information quality attributes
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5 426 of information quality in terms of in- the managing handover information, which is displayed in the central
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7 427 circle of the figure. For example, completeness of information would be ensured by providing a blockchain-
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10 428 based historical record of all transactions and by incorporating smart contracts to detect incomplete
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12 429 information. Blockchain ensures uniqueness as it provides a single source of truth for all participating nodes.
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14 430 Keeping track of all versions of the files and their metadata provides data timeliness, accuracy, and validity,
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16 431 which is strengthened even more by the immutability of blockchain records. The consistency of data records is
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18 432 ensured by smart contracts validating if the information is classified correctly.
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21 433 In As part of the mapping exercise, ~~we did not map one of the root causes~~—leadership impact—~~was not~~
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23 434 mapped to any characteristics of blockchain. ~~—~~The leadership impact caused by the quality deterioration of
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25 435 handover information is not an isolated cause, but support from leadership is necessary to realise the full
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27 436 benefits of implementing blockchain technology to prevent the quality decline ~~in handover information~~.
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29 437 Additionally, Features like ~~we did not map~~ ‘anonymity’ and ‘protection of IP rights’ were also not mapped to
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31 any root causes and information quality dimensions because these features are irrelevant to the handover
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33 438 information management. This exercise culminated in a proposed ~~Based on the mapping exercise, we propose~~
34 439 ~~a~~ conceptual framework for managing handover information irrespective of project size as the asset owners
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36 440 update different assets.
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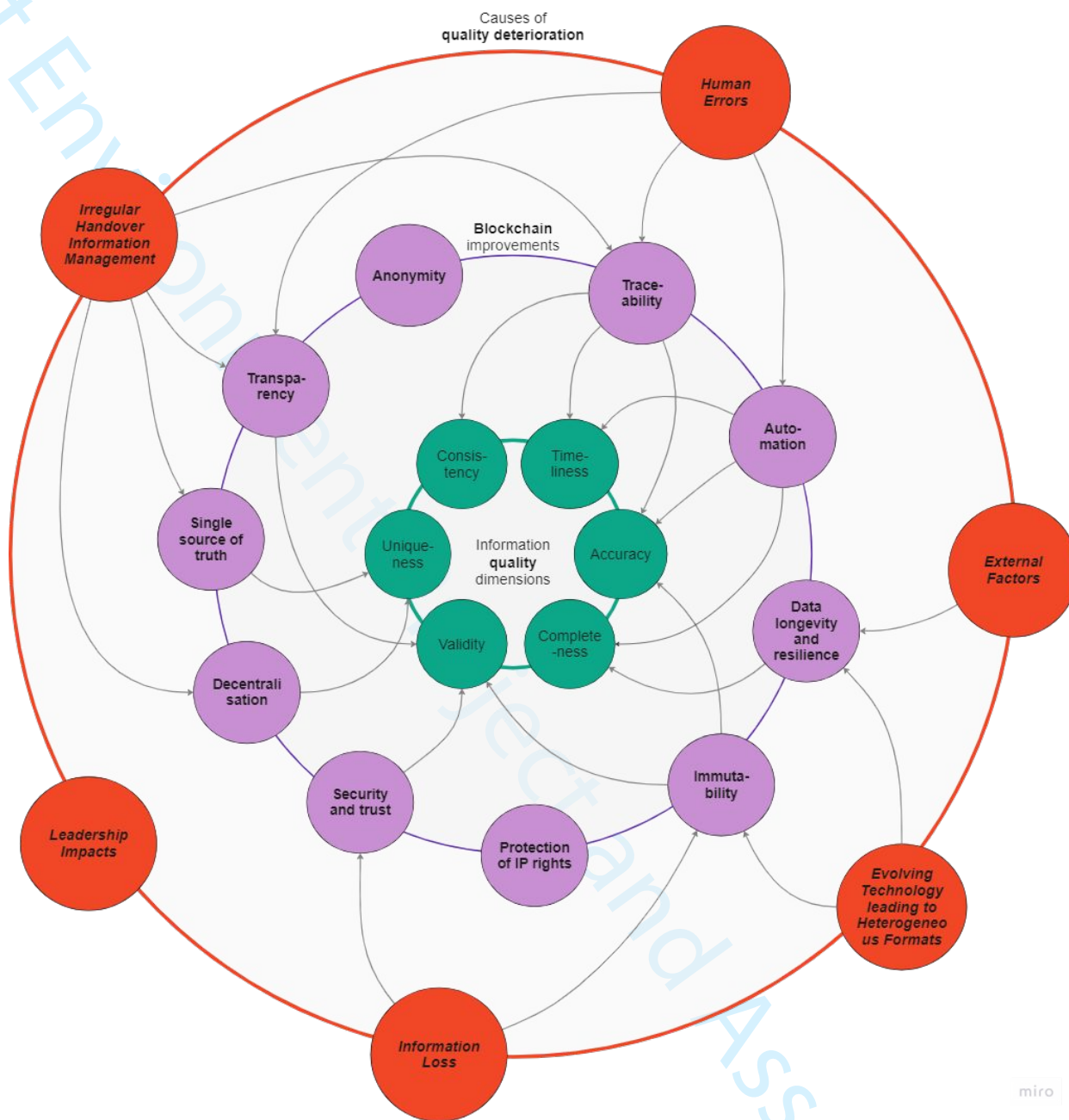


Figure 2. Mapping of root causes, blockchain attributes and data quality dimensions.

4.3 Framework proposal

~~Leveraging blockchain's~~To leverage the benefits, of using blockchain described in the previous section, we propose a conceptual framework is proposed for to facilitate gathering handover information data using blockchain and smart contracts (Figure 3). ~~The process begins with~~ In the first step, the client must defining handover information e the requirements, for handover information, which are then can be encoded into a smart contract. ~~This contract to validates~~ the completeness of uploaded information uploaded by the

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~~contractor. Once the construction phase concludes, Upon receiving the requirements and completing the~~
~~construction phase,~~ the contractor submits the handover information data to the selected cloud platform
 designated by the client. A smart contract ~~is implemented to~~ communicating with the Application
 Programming Interface (API) ~~of the cloud platform, to records~~ all transaction metadata ~~of each transaction~~ on
 the blockchain and checks the information against the ~~while validating the completeness of information~~
~~against previously~~ encoded requirements. If any information is missing, ~~the contractor will be notified by~~
~~smart contract~~ smart contract will notify the contractor and will be urged to repeat to re-upload the necessary
information. After the smart contract confirms the completeness of the submitted information, ~~the process of~~
~~uploading the handover information.~~ When the smart contract approves the completely assembled
~~information,~~ it ~~will then~~ forwards the submitted documents to the architect for review. Once approved, w and
~~approval.~~ Subsequently, the 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.

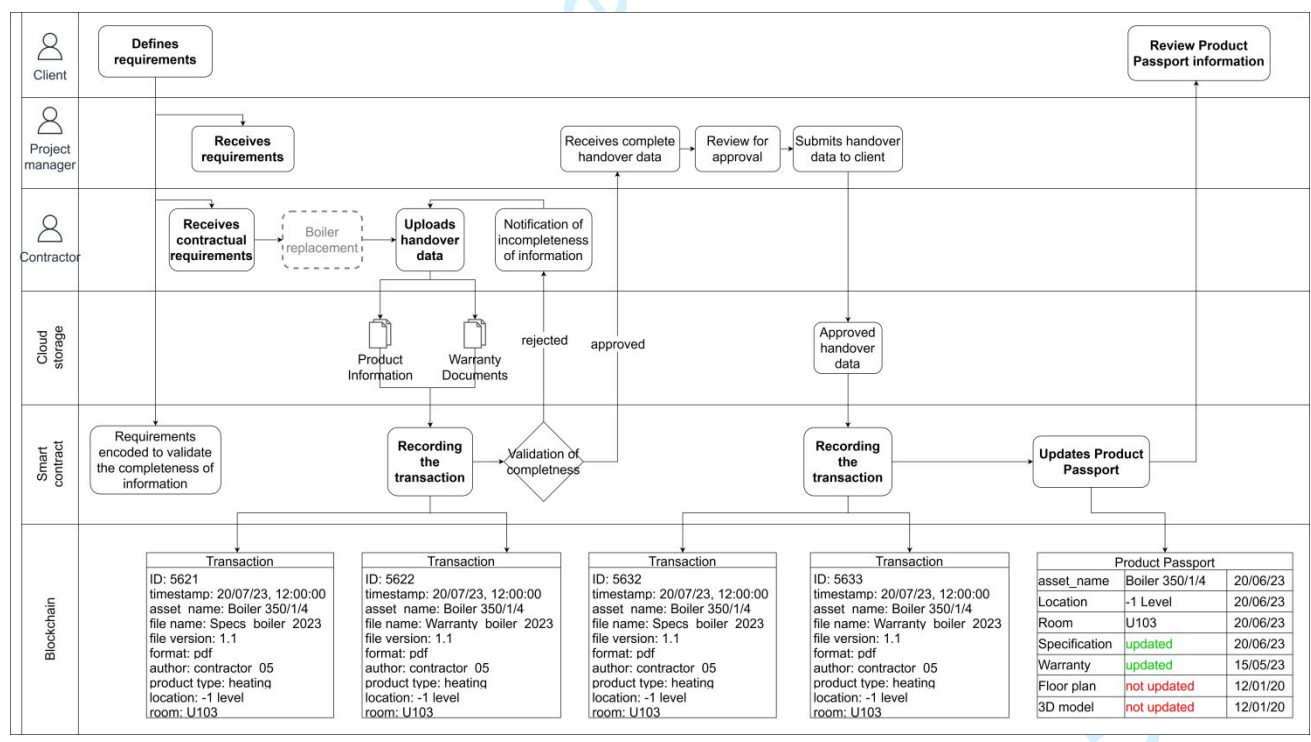


Figure 3. A conceptual blockchain framework of handover information collection process.

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3 465 Furthermore, ~~the we show an example scenario~~ illustrates the use of using blockchain and smart contracts in
4 streamlining the update of to facilitate the process of updating the handover information in a minor project. In
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7 467 the scenario, a contractor replaces a boiler and consequently updates the product specification and warranty
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10 468 documents in the cloud-sharing platform selected by the client. The metadata of the updated information is
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12 469 recorded on the blockchain by the smart contract, which also updates the information in the product passport.
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14 470 For graphical information, such as 2D drawings or 3D models, current technology does not allow encoding
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16 471 the validation of drawings as part of the smart contract, which limits updating in the product passport.
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18 472 Therefore, the client will observe that the drawings or 3D models related to the replacement units are missing
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20 473 from the product passport review.
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23 474 **5 Discussion**

26 475 The investigation into handover information management reveals that robust information management is
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28 476 pivotal to maintaining the integrity and quality of information. These findings align with Masood *et al.*
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30 477 (2016), who underscores the critical role of uniform information management processes in ensuring the long-
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32 478 term quality of information. Further compounding these issues, Yilmaz *et al.* (2015) pinpoint the tangible
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34 479 risks associated with physical information loss and the adverse effects of outdated and ineffective record-
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36 480 keeping methods on the quality of handover information.
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40 481 Transitioning to the broader context, information is constantly evolving through major and minor projects,
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42 482 ranging from extensive renovations to equipment replacements. Each project represents a transactional update
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44 483 event, where accuracy is critical to prevent cascading issues. Love *et al.* (2018) stress the importance of
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46 484 precision in maintaining as-built drawings. Despite the critical nature of managing transactional updates, the
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48 485 task of updating graphical information and corresponding non-graphical information remains vulnerable,
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50 486 mainly due to its reliance on manual updates. This vulnerability stems from the ingrained nature of asset
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52 487 information management in current workflows. Further, there is a notable knowledge gap concerning the
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54 488 effects of poor legacy information management and the assimilation of evolving regulatory demands on the
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56 489 quality of information. This indicates underlying systemic issues in information governance, extending
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58 490 beyond technological solutions.
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3 491 Viewed through this transactional lens, blockchain emerges as a potential, though not originally developed as
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5 492 an information management tool. Blockchain addresses specific concerns, such as immutability and
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7 493 decentralisation, which are highly relevant to asset information management. While blockchain cannot create
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10 494 new information or rectify digitalisation errors, it offers a reliable mechanism for tracking the provenance and
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12 495 changes made to asset information. over time, this could lead to the creation of more reliable information.
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14 496 Furthermore, blockchain's immutable nature ensures that every transaction is recorded with the necessary
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16 497 quality for managing the long lifespan of buildings. The adoption of Distributed Ledger Technology (DLT)
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18 498 like blockchain could markedly improve the efficiency in the detailed documentation and tracking of updates
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20 499 with foundational trust in business relationships, especially in the AEC industry (Qian and Papdonikolaki,
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22 500 2020). Our findings reveal that while blockchain technology offers advantages, it cannot completely address
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24 501 the entirety of the identified reasons contributing to the quality deterioration of handover information. One
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26 502 significant limitation lies in the manual process of updating and validating graphical handover information.
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28 503 For non-graphical information, the accuracy of the submitted information can be checked by implementing
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30 504 Optical Character Recognition (OCR) technology, which can convert scanned documents or captured images
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32 505 into machine-readable documents for validation (Lu *et al.*, 2020). Conversely, updating the existing as-built
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34 506 drawings necessitates manual intervention by architects and engineers. This manual process can introduce
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36 507 human errors and oversights, jeopardising essential project details. Such inaccuracies can complicate the
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38 508 management of physical spaces as managing physical spaces hinges on accurately updated drawings for
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40 509 maximising the use of the existing space. As a direct consequence, Case 3 employed an architectural firm to
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42 510 re-establish the as-built drawings of its buildings.

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46 511 It is noteworthy to state that blockchain's security feature is significant, yet this study indicates asset
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48 512 management professionals, especially in higher education, may underemphasise security concerns. (Parn and
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50 513 Edwards (,2019) stressed the need to harness blockchain's security for protecting assets in high-risk
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52 514 environments, such as banks, prisons, and defence facilities. Although resilient, blockchain is not impervious
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54 515 to threats. Yli-Huumo *et al.* (2016) raised a cautionary note about vulnerabilities, such as the '51% attack',
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56 516 where control over half of the network could lead to blockchain manipulation. This risk illuminates the
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58 517 necessity for vigilant management and robust strategies when implementing blockchain technology. We also
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3 518 ~~discovered that adopting blockchain technology does not inherently create ‘relational trust’ among~~
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5 519 ~~stakeholders (Qian and Papadonikolaki, 2020). This discovery challenges the assertions made by blockchain~~
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7 520 ~~proponents (Wang *et al.*, 2017). Instead, in the realm of building asset management, trust must be established~~
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9 521 ~~before blockchain implementation to harness its potential fully. Conventionally, tasks such as equipment~~
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11 522 ~~repair or replacement require multiple inspections to ensure their completion, especially when the final work~~
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13 523 ~~may not be immediately visible. In such scenarios, an automated approval process demands a pre-existing~~
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15 524 ~~trust with the contractor before blockchain can effectively support building asset management. For example,~~
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17 525 ~~repairing defects identified during electrical wiring integrity testing requires continuous inspections to verify~~
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19 526 ~~the completion of work before releasing the final payment. Alternatively, a building owner might rely on their~~
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21 527 ~~trust in the contractor’s integrity.~~

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25 528 In sum, it is critical to weigh blockchain’s benefits against its limitations and consider its function in an
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27 529 extensive operational context. Key aspects include fostering trust and developing an integrated strategy to
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29 530 handle assets’ amassed digital and physical information. Utilising blockchain to enhance transactional and
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31 531 provenance tracking in asset management can significantly improve information quality.
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38 533 ~~Given these challenges, this study offers theoretical and practical contributions. Theoretically, blockchain~~
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40 534 ~~technology is considered a disruptive innovation; however, it may not entirely resolve the reported quality~~
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42 535 ~~dilemmas due to the inherent complexities of managing handover information. Moreover, this innovation does~~
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44 536 ~~not completely disrupt the existing information flow and the associated processes within each case. From the~~
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46 537 ~~managerial standpoint, the proposed framework presents an opportunity for each case to re-engineer its~~
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48 538 ~~process of managing handover information, particularly as-built drawings, to sustain its quality. By leveraging~~
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50 539 ~~blockchain technology’s unique capabilities, organisations can improve the quality of handover information;~~
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52 540 ~~however, each organisation must explore and implement potential solutions that can bring benefits in~~
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54 541 ~~preventing quality deterioration in handover information.~~

57 58 542 **6 Conclusions**

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3 543 This research's evidence-based case study approach identified the root causes of handover information quality
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5 544 deterioration based on multiple cases. A blockchain-based framework was then proposed to improve the
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7 545 management of handover information, aligning the identified root causes with blockchain features and
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9 546 information quality dimensions. Then, we proposed a blockchain-based framework to facilitate the
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11 547 handover information management processes after mapping the identified root causes, blockchain features,
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13 548 and information quality dimensions. This approach, was not preceded-presented in previous studies,
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15 549 highlights the unique challenges and limitations of implementing blockchain technology in the management of
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17 550 asset information, proposing blockchain-based solutions, revealing challenges and limitations associated with
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19 551 implementing blockchain technology in managing asset information, including building handover
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22 552 information.

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25 553 This study offers theoretical and practical contributions. Given these challenges, this study offers theoretical
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27 554 and practical contributions. On a theoretical level, it positions blockchain technology as a potentially
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29 555 disruptive innovation yet acknowledges its limitations in fully addressing the complexities of handover
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31 556 information management. It challenges the assumption that blockchain can entirely overhaul existing
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33 557 information flows and associated processes in the cases studied. Theoretically, blockchain technology is
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35 558 considered a disruptive innovation; however, it may not entirely resolve the reported quality dilemmas due to
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37 559 the inherent complexities of managing handover information. Moreover, this innovation does not completely
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39 560 disrupt the existing information flow and the associated processes within each case. From the managerial
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41 561 standpoint, the proposed framework presents an opportunity for each case to re-engineer its process of
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43 562 managing handover information, particularly as-built drawings, to sustain its quality. By leveraging
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45 563 blockchain technology's unique capabilities, organisations can improve the quality of handover information;
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47 564 however, each organisation must explore and implement potential solutions that can bring benefits in
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49 565 preventing quality deterioration in handover information.

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57 567 Practically, the study provides managers and practitioners with a framework to improve the quality of the
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59 568 handover information management process using blockchain technology. The study highlights the need for
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3 569 organisations to tailor blockchain solutions to their specific needs, ensuring effective enhancement of the
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5 570 information quality. The research underscores the importance of bespoke strategies in integrating blockchain
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7 571 technology to prevent quality deterioration in handover information, illuminating the practical implications.

10 572 Building on vital

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14 573 Although the unique approach of this study uncovered compelling results, this study is limited to identifying
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16 574 the quality decline in insights from asset management professionals, this study proposes a conceptual
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18 575 framework for managing handover information. However, this study poses certain limitations. Its scope is
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20 576 narrowly confined to information management in asset management, excluding a facilities management
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22 577 perspective. A notable challenge identified is the extensive outsourcing of facilities management tasks in the
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24 578 participating organisations, a trend noted by (Adhikari *et al.*; (2019)). Consequently, future research is
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26 579 essential to evaluate blockchain's productivity and cost-benefits for developing a refined prototype or proof of
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28 580 concept. Such research is crucial for a broader scale, including by third-party service contractors accessing
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30 581 and updating asset information.

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37 583 handover information during the post-construction phase within higher education institutions. This study also
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39 584 proposed a conceptual framework for managing handover information, however; it is worth noting that the
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41 585 scope of this study did not include the technical implementation of the suggested framework. This study's
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43 586 framework must be thoroughly examined to demonstrate its significance. Further research is required to
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45 587 understand how blockchain might increase productivity and subsequent evaluation of the cost-benefit factors
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47 588 associated with such a solution. Future efforts should focus on choosing the best blockchain solution,
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49 589 including creating a refined proof of concept or prototype for broader, practical applications.

52 590 7 Acknowledgement

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Table 1. Principles of blockchain.

	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 <i>et al.</i> , 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 <i>et al.</i> , 2020) (Hijazi <i>et al.</i> , 2021) (Penzes, 2018) (Wang <i>et al.</i> , 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 <i>et al.</i> , 2020) (Hijazi <i>et al.</i> , 2021) (Penzes, 2018) (Wang <i>et al.</i> , 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 <i>et al.</i> , 2020) (Hijazi <i>et al.</i> , 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 <i>et al.</i> , 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 <i>et al.</i> , 2021) (Penzes, 2018) (Wang <i>et al.</i> , 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 <i>et al.</i> , 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 <i>et al.</i> , 2020)

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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 <i>et al.</i> , 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 <i>et al.</i> , 2020)

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Built Environment Project and Asset Management

Table II. Summary of the selected cases.

Case study	Description	Country
1	This public collegiate research university was founded circa 1209 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 1592 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 overseas 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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Built Environment Project and Asset Management

Table III. Participant profiles.

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 & 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 & Electrical Systems	Ireland
	C2_P6	Estates Management	Ireland
	C2_P7	Water Quality	Ireland
3	C3_P1	Space Management	UK
	C3_P2	Mechanical & Electrical Systems	UK
	C3_P3	Mechanical & Electrical Systems	UK
	C3_P4	Estates Management	UK
4	C4_P1	Campus Planning & Space Management	N. Ireland
	C4_P2	Space Management	N. Ireland
	C4_P3	Property Insurance	N. Ireland
	C4_P4	Mechanical & Electrical Systems	N. Ireland

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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 & Safety Systems	N. Ireland
C4_P9	Capital Projects	N. Ireland
C5_P1	Space Management	Germany
C5_P2	Fire, Life & Safety Systems	Germany
C5_P3	Mechanical, Electrical & Fire Systems	Germany
C5_P4	Mechanical & Electrical Systems	Germany
C5_P5	Mechanical & Electrical Systems	Germany
C5_P6	Space Management (Portfolio Planning)	Germany

Revisions Summary: BEPAM-08-2023-0152

Reviewer 1

Item	Categories	Reviewer's comment	Corresponding line numbers	Revision
<p>Dear Professor Kumaraswamy, Associate Editor & Reviewers, We are grateful that you have given us an opportunity to refine the manuscript. The constructive feedback received has undoubtedly improved the quality of our work. Thank you again for considering our work.</p>				
1a	Overall	Avoid the use of first-/second-person pronouns like "we, I, our, me, his" in the paper.		The manuscript is revised to eliminate first- and second-person pronouns to ensure a more formal and objective tone throughout.
1b	Acknowledgement	No content in the "Acknowledgements" section, so delete it.	Lines 441 - 444	<p>The 'Acknowledgement' section is updated:</p> <p>This work was supported by the XXXXX-XXXXX XXXXXXXX XXXXXXXXXXXXX XXXXXXXX (XXXX) European Training Network funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. XXXXXX.</p>
2	Abstract & keywords	<p>What research method/design was employed? This should be stated here.</p>	Lines 11 - 16	<p>The design/methodology/approach section has been updated to include a detailed description of the methodology employed in this study:</p> <p>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.</p>
3	Introduction	There is no discussion on blockchain in this section - being a key part of the paper.	Lines 36 - 60	Lines 37 – 49 have been revised to elucidate why robust information is essential and to explain why BIM is

<p>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47</p>			<p>insufficient, particularly considering the existing buildings predate the BIM era:</p> <p>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 per cent of the total building stock annually (Roberts <i>et al.</i>, 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.</p> <p>Lines 50 – 60 have been newly inserted to introduce blockchain technology as a viable solution:</p> <p>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</p>
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1				network among its participants (Mukherjee and Pradhan, 2021a). 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 <i>et al.</i> , 2020). Its capacity to provide audit trails illuminates transparency and accountability (Mahmudnia <i>et al.</i> , 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 <i>et al.</i> , 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 <i>et al.</i> , 2005).
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18	4a	Literature review	Provide the full meaning of the various abbreviations at their first mention within the body of the manuscript. * What is DIKW?	Lines 86 - 87 The manuscript clarified the abbreviation DIKW: 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).
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26	4b		A new sub-section should be included to discuss the application of blockchain in other aspects of construction processes - apart from handover information management.	Lines 161 - 171 Section 2.4 – Applications of blockchain in the AEC industry was newly inserted to discuss the application of blockchain apart from handover information management. 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 <i>et al.</i> , 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 <i>et al.</i> , 2020). Moreover, blockchain applications extend to improving supply chain management and progress payments in construction to avoid construction delays
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1				(Ahmadisheykhsarmast and Sonmez, 2020; Qian and Papadonikolaki, 2020). Beyond construction, Götz <i>et al.</i> (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 <i>et al.</i> , 2019).
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10	4c		In Section 2.3 (lines 147 and 166), the authors gave two different descriptions for the same Table I. This should be clarified.	Line 159 The description of Table I has been updated: Table I Principles of blockchain.
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14	5a	Results and discussion	Section 4.1 and its sub-section which discusses the six root causes categories lacks relevant references.	Lines 236, 252, 268, 303, & 314 Section 4.1 includes appropriate references. Line 236 - Woodall <i>et al.</i> (2013) Line 252 - (Love <i>et al.</i> , 2018) Line 268 - Yilmaz <i>et al.</i> (2015) Line 303 - (Yilmaz <i>et al.</i> , 2015). Line 314 - (Masood <i>et al.</i> , 2016)
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21	5b		In Section 5: The result findings should be discussed in conjunction with previous studies findings - how they support or negate the results here.	Lines 318-324: 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. Lines 380-385: 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 <i>et al.</i> (2016), who underscores the critical role of uniform information management processes in ensuring the long-term quality of information. Further compounding these issues, Yilmaz <i>et al.</i> (2015) pinpoint the tangible risks
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				<p>associated with physical information loss and the adverse effects of outdated and ineffective record-keeping methods on the quality of handover information.</p> <p>Lines 396-405: 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 Papdonikolaki, 2020).</p>
6	Conclusions	What are the practical contributions (including the theoretical and practical implications) of the study to knowledge and practice?	Lines 424 - 432	<p>The conclusion section has been updated to include theoretical and practical contributions of this study:</p> <p>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.</p> <p>Practically, the study provides managers and practitioners with a framework to improve the quality of handover information management process using blockchain</p>

				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.
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Reviewer 2

Item	Categories	Reviewer's comment	Corresponding line numbers	Revision
1	Introduction	The introduction section should ideally mention some benefits and/or properties of the blockchain technology that can hint at it as a promising venue that demands further investigation. Right now, the introduction reads in a manner that suggests that we should look for potential of blockchain simply because BIM is not promising enough. It's agreeable that BIM implementation is facing issues, but does that suggest that we should look for blockchain to complement it? I believe that the introduction section can be improved here.	Lines 36-49 Lines 50-60	<p>Lines 36-60 have been revised to elucidate why robust information is essential and to explain why BIM is insufficient, particularly considering the existing buildings predate the BIM era:</p> <p>Lines 36-49: 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 per cent of the total building stock annually (Roberts <i>et al.</i>, 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</p>

				<p>Commission, 2020). This situation illuminates the urgency of addressing existing shortcomings in practices, particularly emphasising the vital importance of trustworthy handover information.</p> <p>Lines 50-60 have been newly inserted to introduce blockchain technology as a viable solution:</p> <p>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, 2021a). 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 <i>et al.</i>, 2020). Its capacity to provide audit trails illuminates transparency and accountability (Mahmudnia <i>et al.</i>, 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 <i>et al.</i>, 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 <i>et al.</i>, 2005).</p>
2		<p>Lines 88, 129 – DIKW and DAMA respectively – please provide the expanded version of these abbreviations. Likewise, please ensure that each abbreviation is addressed appropriately at its first mention.</p>	<p>Lines 86-87</p> <p>Line 125</p>	<p>The manuscript clarified the abbreviations DIKW & DAMA:</p> <p>Lines 86-87: 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).</p> <p>Line 125: Combining the English and Wang and Strong's approaches, the Data Management (DAMA) UK Working</p>

1				Group published six core quality dimensions, including the definitions and the related characteristics:
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6	3	Line 129 - ... Want and Strong's ..., please correct it to Wang and Strong's	Line 125	Combining the English and Wang and Strong's approaches
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8	4	Line 147 – What is “>>” for just beside the mention of Table 1?	Line 159	Removed ‘>>’ Table II Principles of blockchain.
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11	5	Lines 147-149 – It is not appropriate to mention that Table 1 summarises characteristics of blockchain that are beneficial in managing handover information. It is right to say that Table 1 mentions characteristics of blockchain. Whether they are beneficial in managing handover information or not is yet to be established.	Lines 142-143	Per the comment, the manuscript updated the description of Table I: For a succinct overview, Table I summarises the salient features of blockchain relevant to information management, complemented by practical examples and implications.
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20	6	A fundamental question that needs to be answered is why should we even consider blockchain for asset handover information? Is that information in anyway sensitive or susceptible to be tampered with in a way that there is a possibility of loss of integrity of information in any way? Is there any evidence? This may be discussed in the introduction section to justify the selection of blockchain technology as a technology to be investigated for asset handover information.	Lines 36-60	The authors have addressed Comments 6 & 7 by revising the introduction section of this manuscript. The revise introduction highlights the significant issues arising from pervasive deficiencies in information management practices, leading to detrimental consequences. While BIM possesses potential in this realm, its effectiveness is limited due to a low adoption rage and its primary application in new construction projects, rendering it impractical for managing asset information of existing buildings that predate the BIM era. Too substantiate this point, the authors refer to building statistics from the 2020 EU Commission report, emphasising the critical need for improved information management. This includes a particularly focus on the crucial importance of reliable handover information, with is essential for the long-term sustainability of buildings.
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32	7	ISO 19650 provides a detailed process for information management using BIM. Procedures for version control and collaboration among stakeholders are well defined as well. An intricate Common Data Environment (CDE) can be setup by the client to provide transparency, traceability, single source of truth, and perhaps immutability as well. How is it exactly that the introduction of blockchain will complement the information management aspect?		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
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				<p>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 per cent of the total building stock annually (Roberts <i>et al.</i>, 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.</p> <p>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, 2021a). 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 <i>et al.</i>, 2020). Its capacity to provide audit trails illuminates transparency and accountability (Mahmudnia <i>et al.</i>, 2022).</p> <p>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 <i>et al.</i>, 2019). Offering a secure, uniform, and</p>
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				<p>transparent approach, blockchain stands out as a suitable alternative to traditional centralised systems, improving the quality of the information (Love <i>et al.</i>, 2005).</p>
8		<p>It is also not clear how other characteristics of blockchain are in any way useful for asset information handover. The mapping exercise seems to be purely an effort by the authors whereby any explanations provided may be the authors views only. It will be beneficial if the authors can consider interviewing some facilities management experts to individually discuss characteristics of blockchain and then ask them to verify how these characteristics can serve them in solving the issues that have been identified. Developing a map thereafter will be more understandable</p>	<p>Lines 406-412 Lines 433-440</p>	<p>In response to this comment, the authors address this comment in two different places in the manuscript as it fit.</p> <p>Firstly, we address the other feature of blockchain necessary to manage sensitive facilities yet still poses vulnerability in the discussion section, Lines 980-986:</p> <p>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 <i>et al.</i> (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.</p> <p>Secondly, we provided two reasons for excluding facilities management perspectives in this study in the conclusions (Lines 433-440), combining these reasons for initiating future study.</p> <p>Reason 1. The scope of this study is narrowly focused on the asset management of higher education sector.</p> <p>Reason 2. All participating organisations outsourced large portions of facilities management task to multiple 3rd party service contractors.</p> <p>However, we believe that future study encompassing a broader scale of blockchain research would be beneficial.</p>

Associate Editor’s Comments

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	1 Overall	Although the authors have submitted an interesting paper, the paper needs to be substantially re-written and improved before it can be further considered for the journal. Based on the comments and feedback from the two reviewers both recommending "Major Revision", much more concerted efforts are needed from the author(s) to revise, clarify, enhance and upgrade the overall contents and presentation of the paper to a level suitable for publication in this journal - Built Environment Project and Asset Management (BEPAM). I therefore recommend that the paper may be considered for possible publication if the authors can revise and re-submit after responding to those comments and suggestions provided by the two reviewers to their satisfaction.	In addition to the reviewer's comments, the authors revised the following sections to clarify and enhance the quality of the manuscript: Lines 5-10: 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. Line 65-76: 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 <i>et al.</i> , 2019; Syafar <i>et al.</i> , 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. Lines 193-196: This study adopted a case-based approach for in-depth investigations in a real-world context, ideal for small sample sizes (Patton, 1999; Saunders <i>et al.</i> , 2019).
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			<p>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.</p> <p>Lines 318-324: 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.</p> <p>Figure 2 was updated to enhance the clarity.</p> <p>Lines 357-367: The authors provided the description of the new figure: Leveraging blockchain’s benefits, a conceptual framework is proposed for gathering handover information using blockchain and smart contracts (Error! Reference source not found.). 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) of the cloud platform, records transaction metadata on the blockchain and checks the information against the encoded requirements. If any information is missing, the contractor will be notified by smart contract to re-upload the necessary information. After the smart contract confirms the completeness of the submitted information, it forwards the submitted documents to the</p>
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			<p>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.</p>
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Editor-in-Chief's Comments

1	Overall	<p>Authors now have an opportunity to rework some areas as advised, and revise as necessary, the weak and unclear parts of the work and presentation as identified by both Reviewers and the Associate Editor in charge. This should enable authors to carefully compile and incorporate critical Major Revisions to this submission.</p> <p>Please also note the following:</p> <ol style="list-style-type: none"> 1. Overall Wordcount: Carrying out the recommended revisions properly is very important, before the next review and this will require extra text. We note that the present wordcount is 8,461 so there is only a little 'space' (39 words) left to include revisions already within the usual 8,500 wordcount limit. <p>However, to ensure that this is done properly in this case, given some serious/significant comments, we are extending the BEPAM wordcount limit of 8,500, to a Total of 8,900: for adding all the important improvements and 'value' to your revised paper, so as to enable authors to carefully and completely address the many specific and constructive comments and recommendations of the Reviewers. Reminder: 280 words must be added, for EACH Fig. (if any) & Table as in Author Guidelines.</p> <p>If any more space is needed, in order to stay within this extended limit, the authors would also need to trim non-essential text/ parts.</p>	<p>This manuscript includes a total of 8,852 words:</p> <ul style="list-style-type: none"> Title: 14 Abstract & keywords: 235 Introduction: 739 Lit review: 1248 Methodology: 530 Findings: 1977 Discussion: 498 Conclusions: 295 Acknowledgement: 35 References: 1601 Tables (X3): 840 Figures (X3): 840
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