Information Quality for Effective Asset Management: A literature review

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Abstract: Information quality is critical to successful asset management decision-making. Substandard quality information will likely cause significant negative short- and long-term consequences. The ongoing digital transformation in the Architecture, Engineering, and Construction (AEC) industry has influenced ways to manage physical assets. Yet many asset owners lack a clear understanding of identifying indispensable quality dimensions that satisfy the business, system, and technical requirements. This paper aims to comprehensively analyse asset information quality management with a systematic literature review. The study reveals that the quality dimension of 'accuracy' alone cannot support various asset management functions. Additionally, quality deficiencies remain in Building Information Modelling (BIM)-based project delivery handover documents, establishing insufficient asset baselines for future planning. Moreover, the limited knowledge on the quality complications of information generated through technical solutions suggests additional work is required to gain insights into vital quality dimensions. The findings of this study underpin the basis for classifying quality dimensions to support essential asset management processes while pointing to future study areas.

Keywords: Information Quality, Data Quality, Asset Information Management, Asset Management, Building Information Modelling

1. INTRODUCTION

Asset management involves realizing the expected performance of all types of assets – tangible and intangible – through the asset owner's coordinated efforts of managing risks, balancing costs, and seeking opportunities to yield greater value from assets (The International Organization for Standardization, 2014). Asset management is not a new discipline. Though the concept of asset management is well-trenched in the financial sector, the private and public sectors in different parts of the world did not relate this discipline in managing physical assets until the 1980s. Since then, the concept of asset management has continued to develop fundamental and complex principles to maximize the full potential of physical assets in various sectors (The Institute of Asset Management, 2015).

Asset management is a data-intensive discipline that many asset-intensive businesses recurrently integrate quality asset information from a wide range of sources to inform decisions at different levels: strategic, tactical, and operational decisions (Fang et al., 2022). Strategic decisions focus on long-term asset strategy and efficiency at an organizational level (Gavrikova et al., 2020). While the attentions surrounding functional asset management of particular activities support mid-term tactical decisions, daily maintenance activities inform operational decisions (Cecconi et al., 2017).

Asset information can be mainly categorized into static and dynamic for complex-built assets like commercial buildings. Static asset information refers to formal handover documents from the construction phase consisting of the project's geometric and non-geometric information (ISO Technical Committee, 2021). Reliable and valid handover documents are necessary because they establish a baseline of the newly constructed assets for future planning (Abdirad and Dossick, 2020). Conversely, the dynamic asset information includes continuous (sensor data), periodical (e.g., inspection reports), and irregular (e.g., unexpected failure of the asset) (ISO Technical Committee, 2021). The primary purpose of collecting dynamic data is to support day-to-day routine building operations. Such information includes energy monitoring, recurring inspection reports, and maintenance records. In addition, the development of IoT (Internet of Things) sensors enables the gathering of real-time information to manage building operations, allowing the combination of static and dynamic asset information, which could play a critical role in supporting decision-making (Tang et al., 2019).

While a combination of disparate asset information is a requisite for robust decisions, a lack of understanding of quality dimensions associated with the asset information may impede the data-centric asset management approach. Information quality requirements when using emerging technologies are ill-defined (Broo and Schooling, 2020). Given the potential impacts of poor-quality information, the ISO 8000 series provide data quality frameworks and guidelines for measuring and analysing information quality; however, its approach in data quality management is fragmented. Limited knowledge is available to pinpoint quality attributes needed to manage the long lifespan of commercial buildings. This paper provides a systematic review of literature, gaining a comprehensive understanding of quality information attributes necessary to support data-centric asset management functions.

2. METHOD

Guided by Denyer and Tranfield (2009), the review method of this study follows four critical steps: (1) search, (2) screening, (3) selection, (4) use.

This literature search utilized the Scopus and Web of Science databases, combing keywords such as 'data quality', 'information quality, 'asset management', 'facilities management', 'engineering assets', and 'BIM'. The initial search resulted in 169 and 86 journals from Scopus and Web of Science, respectively, spanning from 2005 to 2022.

The results have been further filtered by the English language, subject areas, and document types. By reading the abstract, highlights, and key scope of each article, the screening process of the searched journals further eliminated irrelevant journals. Excluded were papers that used the keywords in the title or abstract but did not focus on data quality in asset management. This procedure also removed duplications from the total number of journals. This process identified a total of 59 journals and conference papers.

The results of an electronic database search can be insufficient when addressing complicated research topics (Denyer and Tranfield, 2009). Thus, this study performed a manual search of publications conforming to the boundaries of information quality in asset management. The additional search included the following publications: (1) International Organization Standards (ISO) 55000 - Asset Management, (2) ISO 8000-8: Data Quality, (3) ISO 25000: Systems and Software Engineering – Systems and Software Quality Requirement and Evaluation, and (4) Asset Information, Strategy, Standards and Data Management issued by the Institute of Asset Management (IAM). The outlined concepts and principles related to the quality of asset information in these publications are pivotal guidance for this study.

Including additional publications, this study selected the final set of 63 journals, conference papers, standards, and industry publications for analysis.

This study performed the overall research trend analysis after selecting the final set of publications. This study also utilized VOSviewer to perform keyword co-occurrence analyses to identify emerging research trends and the evolution of focal research topics (Tang et al., 2019).

3. RESULTS

3.1 Overview of research trends

The search results reveal no relevant papers from the Scopus and Web of Science prior to 2005. Figure 1 exhibits the distribution of the selected publications from 2005 to 2022 with an upward trend.

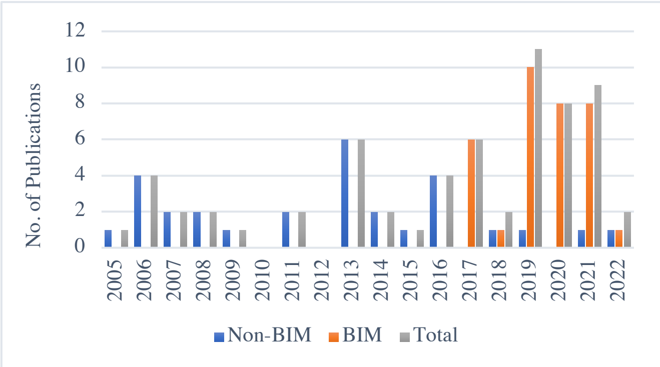

Figure 1. The distribution of 63 publications on information quality in asset management between 2005 and 2022

In early 2000, the research focused on developing varied information quality frameworks for engineering assets. The studies conducted between 2011 and 2014 viewed information quality management through the lens of risk management, evaluating potential impacts of poor quality to the business. With this approach, some scholars developed different approaches to assess the quality of information. For example, Woodall et al. (2013) proposed a hybrid method of evaluating the information quality of the selected activities through validation processes. Additionally, Parlikad et al. (2013) conducted a case study to understand the organizational strategies for information quality management. Further, Borek et al. (2014) established extensive processes for effectively managing the risks associated with information.

Since 2017, the BIM adoption has influenced the research directions in the asset management domain in the built environment. A significant increase is shown in 2019, focusing on BIM-based asset management, emerging technologies to improve asset management activities, and BIM-based data management to support operations. Among the results, Table 1 summarizes the BIM and non-BIM-based publications between 2017 and 2022.

Table 1. Comparison of BIM- and non-BIM-based publications

Year	2017	2018	2019	2020	2021	2022
Non-BIM based	0	1	1	0	1	1
BIM-based	6	1	10	8	8	1
Total Publications	6	2	11	8	9	2

The literature search resulted in only two journals written in 2022 because the search was conducted in March 2022.

3.2 Keyword co-occurrence

Figure 3 reveals the trending research topics in information quality in asset management between 2005 and 2022, showing from the dark blue to yellow representations. In this network, the top five frequently used keywords were "asset management", "information management", "data quality", "information quality", and "BIM". In addition, for the frequency of BIM, this study amalgamated the occurrence of all keywords representing BIM, such as "building information model", "building information modelling" and "BIM".

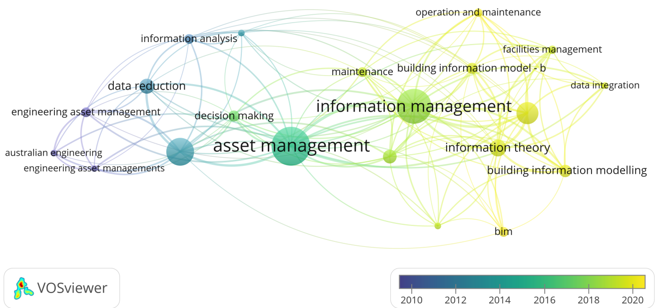

Figure 2. Keyword co-occurrence network based on the timeline

Figure 2 reveals that the most repeated keyword, "asset management", was linked to other frequent keywords mentioned earlier. It is likely that asset management has been studied in concert with other disciplines like information science, information management, and quality management due to utilizing dissimilar asset information to support a wide range of asset management functions (Farghaly et al., 2018).

This study also considered the evolution of the keywords based on the established timeline to evaluate the trends in the research. Figure 2 shows that keywords advanced from "data quality" and "engineering assets" to "information management" and "BIM" in asset management. This phenomenon is due mainly to BIM adoption in the AEC industry, influencing the post-construction phase. The keyword co-occurrence network also suggested that the current trend is to maximize the BIM project delivery information to support managing assets. However, the trending research topics post-2016 showed fewer connections to keywords related to data quality.

In addition to the keyword co-occurrence analysis, the content analysis of the chosen literature formed three areas of the study, which will be discussed in the following section.

4. DISCUSSION

4.1. Asset information from heterogeneous sources

Despite the complexity of a building, asset information generally stems from two primary sources – handover documents and voluminous operation-related information from heterogeneous sources like sensors, building management systems, etc. (Cavka et al., 2017; Thabet and Lucas, 2017).

The handover documents encompass as-built drawings, building component performance data, operation and maintenance manuals, asset inventory lists, and commissioning reports (Abdirad and Dossick, 2020). The recent adoption of BIM project delivery includes non-traditional handover documents like COBie (Construction Operations Building Information Exchange) for transferring asset information to asset owners (Thabet and Lucas, 2017). COBie is an information spreadsheet that includes a mixture of hierarchical and connected assets such as contacts, location, system, component, etc. (Kumar and Lin, 2020). One of the challenges with using COBie is that the connection among multiple spreadsheets makes it difficult to extract the necessary information for specific asset management functions (Kumar and Lin, 2020; Thabet and Lucas, 2017). Despite ample asset information provided in multiple spreadsheets, the COBie by itself is insufficient to manage commercial buildings (Rogage and Greenwood, 2020).

Various tools and devices are utilized to collect continuous operation-related information to support the building operations and enhance asset management decisions (Lu et al., 2019). For example, real-time data through IoT sensors provide a holistic understanding of building performance management, energy management, and indoor environmental quality (Anil et al., 2013). In addition, Radio frequency identification (RFID) tags or 2D barcodes help identify fixed and movable assets using a mobile device. At the same time, a global positioning system (GPS) enables tracking devices linked to a geographic information system (GIS) to manage location-sensitive assets covering a larger area like utility assets (Tang et al., 2019).

An intelligent asset management system is necessary for the effective management of various asset information because of its dissimilar formats. Such asset management systems include, but are not limited to, Building Management System (BMS), Computerized Maintenance Management System (CMMS), Computer-Aided Facility Management (CAFM), and Electronic Document Management System (EDMS) (Borhani and Dossick, 2020).

The asset information from various sources can provide helpful information for adequate asset management decisión support. However, Bayar et al. (2016) argued that the conversión of information in heterogeneous formats to the desired formats frequently causes degrading the quality of information, suggesting additional studies are needed to identify information quality dimensions central to asset management functions.

4.2. Information quality in asset management

Several studies adopted different approaches to identify a set of data quality attributes for effective asset management decisions. For example, Woodall et al. (2015) utilized a combination of literature review and interviews with the UK asset management practitioners to identify seven essential quality attributes: accessibility, consistency, interpretability, timeliness, accuracy, relevance, and believability. In addition, Zadeh et al. (2017) proposed that completeness, accuracy, consistency, well-formedness, and understandability are essential after evaluating the BIM-based design documents. Further, Fang et al. (2022) conducted a case study adopting a two-way evaluation method to assess quality attributes crucial for non-geometric asset information based on the actual information requirements. The same authors summarized four main categories of quality dimensions: availability, usability, reliability, and relevance. Then, their study further identifies suitable quality attributes under each category: timeliness, credibility, accuracy, consistency, completeness, and fitness. These studies uncovered that a single quality dimension alone is insufficient for the complex nature of asset management processes.

Additionally, different authors use various terms to describe information quality dimensions needed for various asset management functions in the AEC industry. Anil et al. (2013), for example, asserted 'comprehensiveness' to represent information quality. On the other hand, Jylhä and Suvanto (2015) underscored 'availability' after conducting multiple case studies. Table 2 summarizes the definition of the most cited information quality dimensions in the literature in the asset management context.

Several guidelines and standards are also available for data quality evaluation. For example, the Audit Commission's framework to measure asset management data quality underscored accuracy, completeness, timeliness, and consistency (Fang et al., 2022). In addition, the Institute of Asset Management (2015) listed accuracy, validity, completeness, consistency, uniqueness, and timeliness as typical quality dimensions commonly used for data quality evaluation. Data profiling tools can assess validity, completeness, consistency, and uniqueness, but manual checking is required to evaluate the accuracy and timeliness of data (The Institute of Asset Management, 2015). Further, International Organization for Standardization (ISO) 8000 Part 8 – Data Quality – provides an unparalleled view of quality dimensions, including syntactic (conformance to its specified syntax), semantic (uniqueness of data), and pragmatic (conformance to usage-based requirements) quality (The International Organization for Standardization, 2016).

Table 2. The definitions of the selected information quality dimensions

Information Quality Dimension	Sources	Definition
Accuracy	Borek et al. (2014) Woodall et al. (2015)	Recorded values match with the actual values.
Accessibility	Woodall et al. (2015) Broo & Schooling (2020)	Conveniently access and retrieve existing information
Availability	Jylhä and Suvanto (2015) Broo & Schooling (2020)	Readily available and obtainable for use
Completeness	Borek et al. (2014) Zadel et al. (2017)	All needed information is presented
Consistency	Woodall et al. (2015) Zadel et al. (2017)	All information with a consistent representation
Relevance	Woodall et al. (2015)	Appropriate for the specified task
Reliability	Cai and Zhu (2015)	Credibility of information
Timeliness	Boreck et al. (2014) Woodall et al. (2015)	Current information
Usability	Cai and Zhu (2015)	All information meets the user's requirements

Wand and Wang (1996) argued that the frequently cited dimensions are accuracy, completeness, consistency, and timeliness. The literature review, however, suggested that multiple quality dimensions are required to strengthen each asset management process (Fang et al., 2022). Yet, limited knowledge is available on vital attributes supporting various asset management processes. Further, adequate research is needed to understand the quality dimensions of information generated using multiple technological solutions.

4.3. Emergent information quality dimensions

The pervasive digital revolution in the AEC industry has influenced asset owners to utilize technological solutions to manage physical assets. Consequently, some researchers re-assessed quality attributes appropriate for the digital transformation in the asset management field. For example, Broo and Schooling (2020) identified the quality attributes of availability, accessibility, quality, volume, heterogeneity, and longevity from a data user-centric point of view. In addition, their study evaluated challenges associated with collecting information using emerging technologies to highlight the following quality attributes: volume, heterogeneity, and longevity.

The emergence of IoT sensors and cloud computing enables the generation of copious amounts of information at an unprecedented speed from multiple sources. As a result, some researchers discovered valuable information supporting asset management functions is usually embedded within unusable parameters (Munir et al., 2020). Asset owners continue generating an explosive amount of operational information yet rarely collect useful information for analytical purposes (Munir et al., 2020). Broo and Schooling (2020) contented that voluminous information is unnecessary because analytics requires an optimal amount of information to produce plausible results. Therefore, establishing quality metrics to determine the ratio between the volume of information and its effective usage to support asset operations is critical to optimize the magnitude of the information.

Broo and Schooling (2020) also elaborated on challenges associated with obtaining information from heterogeneous sources. The same authors criticized that both the design and operation information of complex-built assets are highly heterogeneous, and the software tools used in the different lifecycle of an asset seldom allow for integration with other tools (Broo and Schooling, 2020). For example, the design software like Revit does not integrate its design data with any asset management system without coordinating software tools like Dynamo (Sadeghi et al., 2019). Moreover, Bayar et al. (2016) refuted that formats used in the project design and delivery are different from those used in asset management. For this reason, many asset owners utilize multiple asset management systems compromising and obscuring comprehensive analytics performance. With the increasing use of intelligent asset management systems, the same authors argued that heterogeneity of asset information can further worsen realizing an asset information's total value (Aziz, 2016).

Finally, Broo and Schooling (2020) discussed the long-term availability of data to support the long lifespan of buildings. In aligning with this finding, Masood et al. (2016) identified causes of information degradation, including ownership change, loss of documents, information misplacement, software upgrade, and changes in obsolete file formats. Considering these findings, the same author proposed a structured information future-proofing assessment approach and identified key hazards to assets due to information degradation in the long term. This is coined with the results of the recent catastrophic building failures in the different parts of the world, implying the significance of longevity of asset information to address safety concerns and manage risks associated with managing assets (Grussing, 2013; Hackitt, 2017).

The existing digital transformation in the AEC industry has propelled the recent study to highlight the emergent information quality dimensions. Though the current study introduced the emergent information quality dimensions, sufficient understanding is necessary to sustain the quality of legacy asset information given the long life of buildings. Moreover, it is imperative to understand how to leverage existing technologies to address issues of information quality management as the development of technological solutions continues to influence the AEC industry.

5. CONCLUSION

This paper contributes to the body of knowledge by presenting insights into information quality suitable for effective asset management. The review of 63 journals and publications highlights a few key points. First, the studies performed during the pre-BIM era (before 2016) identified the quality dimensions necessary to support varied asset management functions but provided scant quality complications related to information generated through emerging technologies like IoT sensors. Second, the keywords co-occurrence analysis uncovered that asset information management embraces the concept of information management to gain efficiency and effectiveness. However, limited knowledge is available to understand the information quality appropriate for BIM-based asset management. Third, emphasis on the quality issues with the handover documents continues regardless of different project delivery approaches. Fourth, asset information from heterogeneous sources remains an obstacle because the total value of useful information is seldom realized, especially when using the information in multiple formats.

This author suggests three potential future research directions in asset management information quality based on the findings. In-depth studies of the possible impacts for utilizing technological solutions to the quality of information are necessary because the adoption of emerging technologies to support a wide range of asset management activities is inevitable. Additionally, identifying the root causes of degrading information quality is crucial to maintaining the long-term credible asset information to manage risks associated with operating physical assets like commercial buildings. Finally, evaluating different options for leveraging emerging technologies is essential to address complications involved in managing information quality.

ACKNOWLEDGEMENTS

The research leading to these results has been fully funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 860555.

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