UTS ePRESS

Construction Economics and Building

Vol. 24, No. 3
July 2024

RESEARCH ARTICLE

Enhancing Asset Management Through Integrated Facilities Data, Digital Asset Management, and Metadata Strategies

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DOI: https://doi.org/10.5130/AJCEB.v24i3.8741
Article History: Received 29/07/2023; Revised 08/01/2024; Accepted 10/03/2024; Published 01/07/2024

Citation: Alkhard, A. 2024. Enhancing Asset Management Through Integrated Facilities Data, Digital Asset Management, and Metadata Strategies. *Construction Economics and Building*, 24:3, 76–94. https://doi.org/10.5130/AJCEB.v24i3.8741

ISSN 2204-9029 | Published by UTS ePRESS | https://epress.lib.uts.edu.au/journals/index.php/AJCEB

Abstract

This research explores the potential of Digital Asset Management (DAM) to enhance asset management practices through the utilization of facility data. The study specifically investigates the integration of metadata sourced from 2,340 facility-related issues reported at a public school in Saudi Arabia. Data spanning a two-year period was extracted from the school's system and subjected to quantitative data analysis to assess the frequency and significance of reported facility issues. This analysis, conducted on data extracted from the school's system in .xls format, aimed to identify patterns and trends in problem types, severity, and reported frequency, offering insights into prevalent challenges encountered in asset management and informing the research objectives. Furthermore, a thorough review of existing literature on digital asset management and metadata integration in Asset Information Modeling (AIM) was conducted. This review involved creating a mind map to organize and visualize key concepts, themes, and relationships identified in the literature. Insights derived from the mind map and broader literature review served as the groundwork for comprehending current practices, challenges, and potential solutions in DAM and AIM. The study aims to identify and evaluate key challenges in asset management based on the analysed facility data, devise a strategic framework for integrating metadata into AIM analysis, with a focus on effective metadata management practices, and design an advanced Digital Asset Management system to integrate facility data and enhance decision-making in asset and

DECLARATION OF CONFLICTING INTEREST The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. **FUNDING** The author(s) received no financial support for the research, authorship, and/or publication of this article.

facility management. Notably, the research proposes a strategic framework for metadata integration in AIM analysis, highlighting effective metadata management practices such as defining metadata requirements, establishing standards, and optimizing capture, storage, and governance practices. The framework also advocates for leveraging metadata for continuous analysis and improvement. Anticipated outcomes encompass improved decision-making in asset and facility management, leading to heightened operational efficiency and effectiveness. This research seeks to contribute to advancements of asset management and optimized metadata usage, ultimately setting a new standard for excellence through the better use of facilities data.

Keywords

Digital Asset Management (DAM); Metadata Integration; Asset Information Model (AIM); Effective Metadata Management; Asset Management; Facilities Data

Introduction

Asset management is a systematic approach to efficiently operate, maintain, enhance, and dispose of various assets as per Støre-Valen and Lohne (2016). The perception of buildings and physical assets, including plant and equipment, has gradually evolved. Professionals and scholars in built asset management (BAM) now recognize that assets should provide value beyond merely maintaining their physical condition as per Støre-Valen and Lohne (2016). RICS (2021) defines public sector BAM as a structured process that ensures the best value for money from property assets, serving the strategic needs of public sector organizations. In the context of healthcare buildings, value is defined as the ability of hospital buildings to create optimal conditions for effective healthcare service delivery as per Støre-Valen and Lohne (2016).

Similarly, organizations increasingly acknowledge that buildings are critical assets for fulfilling strategic objectives, rather than mere shelters for people and activities (Iyer-Raniga, Huovila and Erasmus, 2021). BAM should encompass strategically driven processes throughout the entire building life cycle, including planning, acquisition, maintenance, and disposal or replacement. While planning, acquisition, and replacement involve significant capital investments, often supported by external grants, maintenance activities rely on internal organizational revenue. However, the allocation of budgets for BAM tends to be arbitrary, often reflecting available organizational funds rather than strategic needs. This may be attributed to a lack of understanding of maintenance science, leading organizations to adopt the philosophy of "if it isn't broken, don't fix it." This philosophy was initially articulated by Thomas Bertram, Director of the Office of Management and Budget during the Carter administration in 1977. Consequently, many organizations perceive the maintenance of built assets as a cost burden rather than a value addition as Jones and Sharp (2007) state.

One of the reasons for this perception is the lack of evidence and business tools to align BAM activities with organizational performance. While capital investments in NHS organizations in England are supported by best practice guidance, such as the NHS England business case approvals process and the Capital Investment Manual, there is limited national-level guidance for optimizing day-to-day maintenance activities within estates and facilities divisions. As a result, BAM priorities are often compromised during financially challenging times, leading to the accumulation of maintenance backlogs (Garratt, 2021).

To defend maintenance budgets and prioritize BAM activities, asset managers require decision support tools that can prioritize activities and analyse maintenance patterns within buildings. This paper introduces a conceptual framework that utilizes building information modelling (BIM) to integrate interdepartmental information streams and align BAM decisions with organizational performance. The framework proposes a cloud-based BIM application specifically developed for healthcare organizations. Adding value through BAM involves considering life cycle costs, adaptability, and the strategic involvement of facilities

management, all of which contribute to the overall value for healthcare organizations (Støre-Valen and Lohne, 2016). However, aligning BAM activities with organizational performance is challenging and necessitates understanding the relationships between key performance indicators (KPIs) and BAM plans. An effective performance measurement system should be multidimensional and capable of measuring performance across organizational functions and hierarchies (Neely, et al.,1997).

Various performance measurement frameworks are available to assess organizational success. Keegan, Eiler and Jones (1989) emphasized the integration of cost and non-cost dimensions, as well as internal and external dimensions, into an organization's performance model. The balanced scorecard framework developed by Kaplan and Norton (1992) identified four perspectives for evaluating performance: financial, customer, internal business, and innovation and learning. Brown (1996) proposed a Macro Process Model that measures organizational performance across five stages: inputs, processing systems, outputs, outcomes, and goals. This model is particularly suitable for complex healthcare organizations with diverse services (Støre-Valen and Lohne, 2016).

Integrating BIM into BAM processes can support the alignment of BAM decisions with organizational performance by providing comprehensive data and metadata. BIM's data-driven approach enables asset managers to access detailed information about the physical assets, maintenance activities, and associated costs throughout the building life cycle. By incorporating metadata, such as asset attributes, maintenance history, and performance indicators, asset managers can make informed decisions and prioritize maintenance activities based on strategic objectives. However, in asset and facilities management, the integration of facilities data with Building Information Modeling (BIM) Asset Information Modeling (AIM) stands as a catalyst for optimizing the lifecycle management of buildings and infrastructure projects. This synergy facilitates a seamless transition of data from the construction phase into the operational phase, enriching the BIM/AIM with detailed operational, maintenance, and management insights. Such integration not only streamlines the flow of information, ensuring the accuracy and contemporaneity of data used in facility management but also enhances decision-making processes by providing a comprehensive view of asset performance, maintenance history, and operational needs. The fusion of facilities data into BIM/AIM supports operational efficiency, simplifies maintenance workflows, and underpins data-driven decision-making, thereby enabling more strategic asset management approaches. It aids in proactive maintenance planning, energy usage optimization, and compliance management, ultimately elevating the asset's performance, sustainability, and compliance posture throughout its lifecycle. This integrated approach exemplifies how leveraging digital twins in the form of BIM/AIM, enriched with real-time and historical facilities data, can revolutionize asset management strategies, offering a blueprint for future advancements in the construction and infrastructure sectors.

Furthermore, BIM facilitates the integration of various software applications, such as Computer-Aided Facility Management (CAFM) systems and Computerized Maintenance Management Systems (CMMS), to enhance data sharing and analysis. This integration allows for the development of intelligent tools capable of analysing data and generating multi-criteria models for informed decision-making. With the support of BIM and metadata, asset managers can effectively analyse the interaction between BAM resource consumption, component/unit performance, and overall organizational performance.

In summary, the rationalization of asset management involves aligning decisions related to building asset management (BAM) with organizational performance by utilizing both data and metadata. Integrating Building Information Modeling (BIM) into BAM processes and facilities data enables asset managers to access comprehensive information about physical assets, maintenance activities, and associated costs. The inclusion of metadata facilitates informed decision-making and prioritization of maintenance activities based on strategic objectives. Moreover, through the integration of software applications and the development of intelligent tools, data analysis can be enhanced, leading to the generation of multi-criteria models for effective decision support. This facilities data-driven approach enhances the overall

understanding of how to manage assets in a more comprehensive and low-risk manner. To investigate the effectiveness of such an approach, the researcher conducted a study in the Kingdom of Saudi Arabia to examine how asset data could be better analysed to support improved decision-making, prompt responses, and, ultimately, more effective and efficient asset management. Moreover, the following section discusses studies research methodology.

Literature Review

ASSET INFORMATION MODELING AND MANAGEMENT

Asset Information Modeling and Management (AIMM) has emerged as a significant advancement in the construction and infrastructure industry, transforming the way assets are managed across their lifecycle (Smith, Johnson and Brown, 2017). AIMM leverages the power of Building Information Modeling (BIM) to create a comprehensive framework that combines data, collaboration, and advanced management practices (Lu, Lai and Tse, 2018). BIM serves as a digital twin of physical assets, capturing both geometric and non-geometric information, thus providing a collaborative and data-rich environment for stakeholders involved in asset design, construction, and operation (Abbasnejad, et al., 2021). This integration of BIM in AIMM enables seamless information flow and enhances decision-making at every stage of the asset's lifecycle (Abbasnejad, et al., 2021).

Within the AIMM framework, the utilization of BIM extends beyond design and construction, encompassing the entire asset lifecycle, including operation and maintenance (Salama, et al., 2018). By capturing and managing asset-related information, such as specifications, warranties, maintenance schedules, and performance data, AIMM ensures that assets are optimally utilized and maintained throughout their lifespan (Abbasnejad, et al., 2021). This data-driven approach facilitates effective asset management, reduces downtime, and improves operational efficiency that aligns to meet projects Key Performance Indicators as per (Bhatti, Awan and Razaq, 2014).

AIMM comprises two essential components: the base model and the operation model (França, et al., 2021). The base model captures the initial asset design and construction information, while the operation model records actions and updates made during the project lifecycle, providing an accurate representation of the asset's current state (Eastman, et al., 2011). This integration of base and operation models enables seamless coordination between the design and operation stages, ensuring that the asset model effectively supports operational requirements and data are shared (DC Hub, 2021). Information management plays a pivotal role in AIMM, empowering stakeholders to access accurate and up-to-date data, thus facilitating informed decisions, improving productivity, and minimizing risks (Eastman, et al., 2011).

Moreover, the integration of AIMM with advanced technologies, such as artificial intelligence and machine learning, enhances data analysis capabilities, enabling predictive maintenance and performance optimization (Wanigarathna, et al., 2019). The literature extensively highlights the benefits of AIMM and BIM, including improved collaboration, enhanced quality delivery, strengthened security, fostered innovation, built trust, facilitated information sharing, effective problem-solving, creation of immutable solutions, improved data accuracy, materialized asset-related information, and application of cryptography techniques to secure asset data (Pan and Zhang, 2023).

Furthermore, the coexistence of AIMM with Digital Asset Management (DAM) expands the capabilities of asset management systems, allowing efficient organization and utilization of digital assets alongside the BIM model (Pan and Zhang, 2023). In summary, AIMM stands as a transformative concept in the construction and infrastructure industry, leveraging BIM to enable effective asset management throughout the asset lifecycle. By harnessing data and advanced technologies, AIMM empowers organizations to make informed decisions, optimize asset performance, and drive operational excellence,

while the integration with DAM further enhances digital asset management capabilities, providing a comprehensive solution for organizations to maximize the value of their assets (Pan and Zhang, 2023). Future research in AIMM and DAM integration holds the potential to unlock even greater efficiencies and effectiveness in asset management practices, propelling the industry towards new heights of excellence and innovation.

DIGITAL ASSET MANAGEMENT

Digital Asset Management (DAM) is an emerging field that encompasses the organization, retrieval, and utilization of digital assets for various purposes. In recent years, Asset Information Modeling and Management (AIMM) has gained prominence in the construction and infrastructure industry as a framework for managing assets throughout their lifecycle. This literature review aims to provide a comprehensive overview of DAM and AIMM, including their concepts, principles, and applications. The review draws on relevant literature from reputable sources, including standards, books, and research articles, to highlight the key aspects of DAM and AIMM, their benefits, challenges, and future directions. The findings of this review can serve as a valuable resource for researchers, practitioners, and decision-makers in the field of DAM and AIMM.

Digital Asset Management (DAM) has emerged as a critical field for managing digital assets, which include digital media files such as images, videos, audio, documents, and other multimedia content (Schleicher and Bach, 2016). DAM involves the organization, storage, retrieval, and utilization of these digital assets, enabling efficient and effective management of digital content for various purposes, including marketing, branding, content creation, distribution, and archiving (Gartner, 2019). DAM has gained increasing importance in today's digital era, where the volume and complexity of digital assets are growing exponentially, and organizations are faced with the challenge of managing these assets in a structured and efficient manner.

Digital Asset Management (DAM) encompasses a set of concepts and principles aimed at effectively managing digital assets throughout their lifecycle (Re Cecconi, et al., 2020). Key concepts and principles of DAM include asset organization, storage, retrieval, utilization, preservation, and analytics. Proper organization of digital assets through the creation of metadata, tags, and categories enables efficient asset discovery and utilization, reduces duplication of assets, and ensures consistency and accuracy of asset information (Gartner, 2019). DAM requires the storage of digital assets in a secure and scalable manner, considering factors such as storage capacity, backup and recovery strategies, and access control mechanisms to ensure data integrity, confidentiality, and availability. Efficient retrieval of digital assets through search functionality, filtering, and browsing options, along with advanced features such as artificial intelligence-based asset recognition and recommendation, enhances productivity and ensures the right assets are used for the right purposes (Re Cecconi, et al., 2020). Effective utilization of digital assets involves features such as asset sharing, collaboration, versioning, and rights management to ensure appropriate use and compliance with copyrights, licenses, and legal requirements. Long-term preservation of digital assets through strategies such as format migration, metadata preservation, and adherence to digital preservation standards safeguards assets from obsolescence and data loss. Asset analytics, through data visualization, reporting, and analytics tools, provides insights into asset usage, performance, and Return of Investment (ROI), aiding decision-making, content optimization, and performance evaluation. These key concepts and principles of DAM are crucial for organizations to effectively manage their digital assets, ensuring efficient and compliant use of assets for various purposes.

The concept and principles of digital asset management encompass various aspects to effectively organize, store, retrieve, utilize, preserve, and analyse digital assets within an organization (BuildingSMART International, 2020). Asset organization involves a structured approach that utilizes metadata, tags, and

categories, making it easy to retrieve digital assets when needed (Re Cecconi, et al., 2020). Secure and scalable storage of digital assets, including backup, recovery, and access control, falls under the asset storage principle (Rashmi, et al., 2023). To ensure efficient retrieval, asset retrieval encompasses features such as search, filtering, and browsing options (Rashmi, et al., 2023). Asset utilization focuses on appropriate sharing, collaboration, versioning, and rights management to make the most of digital assets. Long-term preservation of digital assets for accessibility, authenticity, and usability is addressed by the asset preservation principle (Zhou, 2023). Asset analytics provide valuable insights into asset usage, performance, and return on investment through dedicated analytical features (McKinsey & Company, 2019). Asset governance is crucial for establishing policies and processes to effectively manage digital assets within an organization (Xu, et al., 2024). For collaborative work, asset collaboration facilitates activities like review, approval, commenting, and annotations among team members and stakeholders (Wanigarathna, et al., 2019). Finally, asset integration ensures seamless integration of digital assets with other systems and tools within an organization's digital ecosystem (Eastman, et al., 2011). By adhering to these concepts and principles, organizations can efficiently manage their digital assets and harness their full potential to achieve their objectives (Gartner, 2019).

BENEFITS OF DIGITAL ASSET MANAGEMENT

Implementing DAM can provide numerous benefits for organizations. Some of the key benefits of DAM according to the literature review include:

Improved Efficiency: DAM streamlines the process of asset organization, storage, retrieval, and utilization, leading to improved efficiency in managing digital assets. With proper metadata, tagging, and categorization, assets can be easily searched, retrieved, and shared, reducing the time spent searching for assets and improving productivity (Gartner, 2019). Enhanced Collaboration: DAM enables effective collaboration among team members and stakeholders by providing a central repository for storing and managing digital assets. This allows team members to access, review, and collaborate on assets in real-time, facilitating seamless teamwork and reducing communication gaps (Schleicher and Bach, 2016).

Brand Consistency: DAM helps organizations maintain brand consistency by providing a central repository for storing approved brand assets, such as logos, images, and videos. This ensures that only authorized and up-to-date assets are used, reducing the risk of inconsistent branding across different channels and touchpoints (IBM, 2020). Asset Reusability: DAM allows organizations to easily repurpose digital assets across different channels and campaigns, maximizing the value of assets and reducing the need for redundant content creation. This leads to cost savings, improved content consistency, and faster time to market (Gartner, 2019).

Compliance and Rights Management: DAM provides features for managing copyrights, licenses, and usage rights for digital assets, ensuring compliance with legal and regulatory requirements. This helps organizations avoid legal issues, penalties, and reputational risks associated with unauthorized use of assets (Allen, et al., 2020).

Data-Driven Decision Making: DAM can provide analytics and reporting features that enable organizations to gain insights into asset usage, performance, and ROI. This data-driven approach to asset management allows organizations to make informed decisions on asset utilization, content optimization, and performance evaluation, leading to better overall outcomes and improved return on investment (ROI) (Re Cecconi, et al., 2020).

Scalability and Flexibility: DAM systems are designed to handle large volumes of digital assets, making them scalable and flexible to accommodate the growing needs of organizations. As the volume and complexity of digital assets increase, DAM allows organizations to efficiently manage and scale their asset management processes without sacrificing performance or usability (Schleicher and Bach, 2016).

Disaster Recovery and Data Security: DAM includes features such as backup, recovery, and access control mechanisms to ensure data integrity, confidentiality, and availability. This helps organizations protect their digital assets from data breaches, loss, and other security risks, ensuring the long-term preservation and accessibility of valuable digital assets (Gartner, 2019).

In summary, Digital Asset Management (DAM) is a crucial component of modern organizations' digital strategy. It encompasses various processes, including asset organization, storage, retrieval, utilization, preservation, and analytics. Implementing DAM can provide organizations with numerous benefits, including improved efficiency, enhanced collaboration, brand consistency, asset reusability, compliance and rights management, data-driven decision making, scalability, and data security. By effectively managing digital assets, organizations can optimize their content creation, distribution, and utilization processes, leading to better outcomes, increased productivity, and improved ROI. As the volume and complexity of digital assets continue to grow, DAM becomes an essential tool for organizations to effectively manage their digital assets and maximize their value. Further research and advancements in DAM technologies are needed to address the evolving needs of organizations in the digital era.

Case studies can provide real-world examples of how digital asset management (DAM) and Asset Information Modeling and Management (AIMM) have been implemented in organizations to achieve tangible benefits. In the pursuit of organizational excellence, technology has emerged as a transformative force, driving a myriad of advantages across various industries. This academic study presents a comprehensive comparative analysis of four industry-specific use cases, showcasing the remarkable impact of technology adoption on key organizational aspects. Coca-Cola Enterprises, operating in the beverage industry, implemented technology-driven solutions to achieve consistent brand messaging, improved collaboration, increased operational efficiency, and reduced content creation costs (Puravanjkara, 2007). The Metropolitan Museum of Art in the arts and culture domain efficiently organized, stored, and retrieved digital assets, leading to enhanced access and utilization of their collection and facilitating digital preservation efforts through robust metadata management and version control (Zhou, 2023).

In the transportation sector, The Port Authority of New York and New Jersey benefited from real-time asset monitoring, proactive maintenance planning, improved asset performance, reduced maintenance costs, and enhanced safety and security (WSP, n.d.). Getty Images, operating in the media industry, capitalized on technology for efficient organization, cataloguing, and distribution of digital assets. They further improved operational efficiency, accelerated content delivery, and enhanced customer experiences through robust metadata management, version control, and rights management. These industry-specific use cases underscore the transformative potential of technology adoption in organizations. The efficient organization, retrieval, and utilization of digital assets enhance productivity and resource management. The facilitated digital preservation and robust metadata management contribute to long-term knowledge retention and accessibility. Real-time asset monitoring and proactive maintenance planning optimize asset performance and reduce operational costs. Furthermore, streamlined content distribution and enhanced customer experiences foster brand loyalty and competitive advantage. This study highlights the critical importance of embracing technology-driven strategies to achieve organizational success in today's dynamic and competitive landscape and serves as a valuable reference for scholars and practitioners seeking to harness the benefits of technological innovations.

These case studies illustrate how DAM and AIMM have been implemented in diverse industries, including marketing, art and culture, transportation, and media, to achieve benefits such as improved operational efficiency, collaboration, content creation, preservation, and compliance. These real-world examples highlight the value of DAM and AIMM in effectively managing digital and physical assets, leading to tangible outcomes for organizations.

Research Methodology

The research used quantitative data analysis and a review of existing literature to provide insights into digital asset management and metadata integration. The research objectives were formulated based on insights from the data analysis and literature review, guiding the development of an advanced Digital Asset Management system and supporting metadata in Asset Information Modeling analysis.

In particular, an extensive literature review was conducted, delving deep into existing research and best practices in digital asset management, metadata integration, and asset information modelling. the nature of reported asset problems and their potential impact on asset management practices (Smith, Johnson and Brown, 2017). The literature review helped contextualize the research within the broader academic and practical landscape and provided a foundation for developing the research objectives and the proposed integrated strategy Based on the findings from the data analysis and the literature review, the research objective was formulated. The research methodology also addressed potential limitations and considerations related to the dataset, data analysis techniques, and the generalizability of the findings These factors were considered to ensure the robustness and reliability of the research outcomes.

Current Trends and Challenges in Digital Asset Management: The review explored recent advancements, focusing on how modern technologies are reshaping asset management practices. It examined how digitalization and automation are influencing the management of physical assets and the associated metadata.

Metadata Integration Techniques and Their Effectiveness: The literature review scrutinized various methodologies employed in integrating metadata within asset management systems. It critically analysed different integration models, their scalability, and efficiency in various operational contexts.

Digital Asset Management and Asset Information Modeling (AIM): The study reviewed existing frameworks and standards in AIM, emphasizing how they are being utilized in different industries. The review also highlighted gaps in current AIM practices, particularly in handling complex metadata structures.

Case Studies and Best Practices: Drawing on relevant case studies, the review identified best practices and common pitfalls in asset management and metadata integration. It also included a comparative analysis of asset management strategies across different sectors.

In addition, the case study highlights the transformative potential of leveraging real asset facilities management data from a school in the Kingdom of Saudi Arabia to enhance the domain of asset management. It underscores the transition from traditional to digital facilities and asset management methods, emphasizing the necessity for modernization in this field. The primary aim is to shed light on the benefits and requirements of digitalization in managing assets and facilities, rather than establishing the reliability or validity of the findings. A noted limitation of this study is the absence of validation for the proposed digital asset management strategy, indicating a need for further research to solidify these approaches. This study analyse and integrate metadata from 2,340 reported facilities issues, spanning from 2019 to 2022. The goal is to enhance decision-making processes, shorten response times, and boost the overall efficiency and effectiveness of asset management practices, utilizing metadata derived from facilities management data. This dataset included facilities specifications, maintenance schedules, performance data, and other relevant details. A meticulous harmonization process was undertaken to ensure data coherence, consistency, and the elimination of discrepancies, data quality issues, and duplicate entries. The techniques were used to analyse the data are: Trend Analysis (the study involved analysing time-based trends in the reported asset problems, plotting monthly and annual frequencies to uncover patterns or seasonal variations), cluster Analysis (this method grouped similar asset problems to identify common categories, aiding in targeted maintenance strategies development) and anomaly detection (identifying outliers and anomalies, including the removal of duplicate entries and recognizing unusual frequencies of occurrences that might indicate systemic issues).

CONTRIBUTION TO KNOWLEDGE:

The significant contribution of this research lies in its exploration of more effective ways to utilize facilities data, thereby enhancing asset management practices. By integrating facilities data with digital asset management and metadata strategies, this study aims to optimize the management of assets across their lifecycle. Facilities data encompasses a wide range of information related to the physical attributes, usage patterns, maintenance records, and operational metrics of assets. By harnessing this data alongside digital asset management tools and robust metadata strategies, organizations can gain deeper insights into asset performance, improve decision-making processes, and enhance overall operational efficiency. Through the integration of facilities data into digital asset management systems, organizations can ensure a comprehensive understanding of asset conditions, usage patterns, and maintenance needs.

This allows for proactive maintenance planning, optimized resource allocation, and improved asset performance. Furthermore, leveraging metadata strategies enables the effective organization, retrieval, and utilization of both facilities data and digital assets. Metadata provides essential context and structure to the vast amount of data associated with assets, facilitating easier access, analysis, and decision-making. Hence, by adopting an integrated approach that combines facilities data, digital asset management, and metadata strategies, organizations can unlock new opportunities for enhancing asset management practices. This includes streamlining workflows, improving collaboration between stakeholders, and maximizing the value of assets throughout their lifecycle. Overall, this research seeks to provide practical insights and strategies that enable organizations to achieve greater efficiency and effectiveness in asset management.

A Case Study

DATA ANALYSIS

In the process of data integration, several noteworthy observations were made, each holding practical implications for asset management practices. Notably, the researchers identified instances of duplicated data and records within the repository. Such redundancy can lead to inefficiencies and inaccuracies in asset management decisions, emphasizing the necessity for de-duplication measures and streamlined data handling procedures. Furthermore, incomplete or inaccurate entries were prevalent in the data, raising concerns about the reliability and efficacy of asset information. Addressing this challenge entails adopting rigorous data validation processes to ensure the completeness and accuracy of asset-related records. Language issues were also uncovered in the metadata, indicating the significance of standardized terminologies and clear communication channels to establish a common understanding of asset problems and associated matters. Timely reporting of asset problems emerged as a critical area of improvement. Encouraging prompt reporting mechanisms can enhance responsiveness and enable timely resolution of asset issues, mitigating potential downtime and minimizing disruptions to operations. The absence of status reports for certain assets was highlighted as another practical concern. Implementing a robust status reporting system can offer real-time insights into asset conditions, empowering decision-makers with up-to-date information for proactive asset management.

Moreover, the study identified confusion between asset and facilities data, emphasizing the need for precise categorization and classification of information to foster clear distinction and facilitate efficient asset management. By addressing these practical challenges and implementing effective metadata management strategies, asset managers can elevate the accuracy, reliability, and utility of asset information. A comprehensive and cohesive digital asset management approach, enriched with accurate metadata, can facilitate informed decision-making, optimize operational efficiency, and maximize the value of assets

throughout their entire lifecycle. These findings offer valuable guidance for practitioners and scholars seeking to enhance asset management practices in the dynamic landscape of digital asset management.

Moreover, the identified problems in the integration of metadata from the repository of reported asset problems can have significant consequences on asset management practices. Considering the literature review the consequences can be seen below:

Redundant Data: The presence of duplicated data and records can lead to inefficiencies and inaccuracies in asset management decision-making. It can result in redundant efforts, wasted resources, and confusion among stakeholders. According to Neely, et al. (1997), redundant data can distort performance measurement and undermine the effectiveness of management decisions.

Incomplete/Inaccurate Data: Incomplete or inaccurate data can negatively impact the reliability and efficacy of asset information. It may lead to incorrect assumptions and suboptimal asset management strategies. Nguyen and Tran (2024) emphasize the significance of accurate data for successful asset management and highlight that inaccurate data can lead to poor performance and increased costs.

Language Issues: Language discrepancies in metadata can create communication barriers and hinder effective collaboration among stakeholders. A standardized terminology is crucial to ensure a common understanding of asset-related matters. Hire, et al. (2021) discuss the importance of clear communication in construction safety management and how language issues can lead to misunderstandings and safety risks.

Lack of Timely Reporting: Delayed reporting of asset problems can result in prolonged downtime and maintenance delays, impacting operational efficiency. Jones and Sharp (2007) stress the importance of timely reporting for effective asset maintenance and argue that delays can lead to increased repair costs and decreased asset reliability.

Absence of Status Reports: The absence of status reports for certain assets can hinder visibility into their condition and performance. This lack of information may lead to missed opportunities for preventive maintenance and performance optimization. Wanigarathna, et al. (2019) advocate for regular status reporting to improve building performance evaluation and facility management.

Confusion Between Asset and Facilities Data: Misclassification of data between assets and facilities can cause confusion and mismanagement of resources. Clear categorization is essential for making informed decisions about asset maintenance and resource allocation. WSP (n.d.) highlight the importance of effective asset information management to streamline operations and optimize resources.

Based on the study a graph presents the data issues ranked by importance level for asset management as per the case study, with the most impactful issues at the top (Figure 1). This ranking is designed to help prioritize actions and focus on the most significant areas for improvement in asset management practices.

Figure 1. The frequency/importance of problems identified in the case study

The bar graph prioritizes the various data issues according to their importance in the context of asset management, offering a clear visualization to aid in strategic decision-making. At the top of the graph, "Incomplete/Inaccurate Data" is identified as the most critical issue, emphasizing its significant impact on decision-making accuracy and operational effectiveness. Close behind, "Redundant Data" and "Absence of Status Reports" are also highlighted as highly impactful, pointing to their roles in causing inefficiencies and obscuring asset performance visibility. Lower on the scale, "Lack of Timely Reporting" and "Confusion Between Asset and Facilities Data" are still notable concerns, as they can lead to maintenance delays and resource misallocation. Finally, "Language Issues," while having the least impact among the issues listed, is recognized as a potential barrier to clear communication and effective collaboration among stakeholders. This graph is intended to serve as a tool for managers and decision-makers, guiding them to allocate resources and attention efficiently by tackling the most significant data quality issues first. By addressing these issues in order of importance, organizations can systematically enhance their asset management processes, thereby improving overall asset life cycle performance and reducing associated costs.

Hence, addressing these consequences requires a robust metadata management strategy, encompassing data validation processes, standardized terminologies, prompt reporting mechanisms, comprehensive status reporting, and precise categorization of information. By implementing these measures, organizations can enhance the accuracy and reliability of asset information, leading to more efficient asset management practices and improved overall performance. Hence, the following two sessions aim to capture the literature review in the aforementioned domains.

Findings and Discussion

According to the literature review, facilities data plays a crucial role in advancing asset management by serving as a foundational element for Asset Information Modeling and Management (AIMM), a significant innovation within the construction and infrastructure sector. AIMM enhances the management of assets across their lifecycle by integrating Building Information Modeling (BIM) to create a comprehensive framework that combines data, collaboration, and advanced management practices. Facilities data, encapsulating specifications, warranties, maintenance schedules, and performance data, enriches the BIM model, transforming it into a digital twin that mirrors the physical assets with both geometric and non-geometric information. This integration ensures a collaborative, data-rich environment for stakeholders at every stage of an asset's lifecycle, from design through construction to operation.

By leveraging facilities data within the AIMM framework, asset management is significantly enhanced as this data-driven approach facilitates effective management, reduces downtime, and improves operational efficiency. The AIMM model, comprising both a base and an operation model, captures the initial design and construction information and records updates made throughout the asset's lifecycle. This dual-model approach enables seamless coordination between the design and operational phases, ensuring the asset model accurately supports operational requirements and reflects the current state of assets.

Furthermore, facilities data within AIMM allows for the exploitation of advanced technologies like artificial intelligence and machine learning, enhancing data analysis capabilities for predictive maintenance and performance optimization. The integration of facilities data in AIMM empowers organizations to make informed decisions, optimize asset performance, and drive operational excellence by providing a detailed and accurate representation of assets' current and projected states. This is further bolstered by the coexistence of AIMM with Digital Asset Management (DAM), expanding asset management capabilities to efficiently organize and utilize digital assets alongside the BIM model.

In essence, facilities data is instrumental in improving asset management by ensuring the AIMM framework is grounded in accurate, comprehensive, and actionable information. This facilitates a more

strategic, efficient, and effective approach to managing the lifecycle of assets, thereby propelling the construction and infrastructure industry towards higher standards of excellence and innovation.

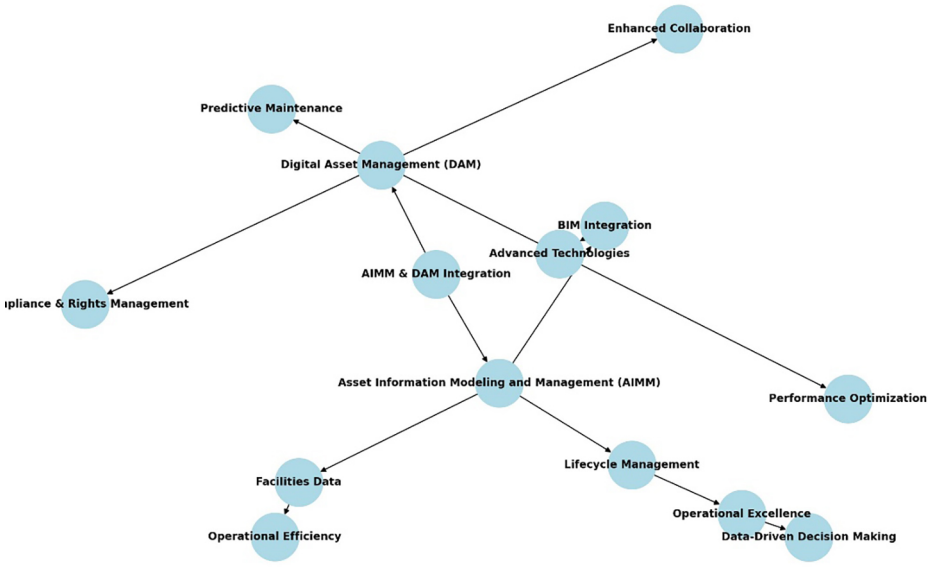

Figure 2. AIMM and Digital Asset Management Integration mind map based on Facilities Data

The mind map (figure 2) above visually represents the integration of Asset Information Modeling and Management (AIMM) and Digital Asset Management (DAM), outlining key components and their interrelations. This map highlights the foundational role of AIMM and DAM in lifecycle management, BIM integration, and leveraging facilities data, all aimed at achieving operational excellence through advanced technologies, predictive maintenance, and performance optimization. Additionally, it underscores the contributions of DAM in enhancing collaboration and ensuring compliance, collectively driving data-driven decision-making and operational efficiency.

However, to integrate meta data for better asset information modelling analysis then a meta data integration for enhanced asset management is proposed (digital asset management). Integrating facilities data into the proposed metadata integration strategy for enhanced Asset Information Modeling (AIM) analysis further enriches the asset management process. This integration is seamlessly woven into each of the nine key stages, emphasizing the pivotal role of facilities data in augmenting metadata's value and utility within the AIM framework (figure 3).

The enhanced strategy is articulated as follows:

Define Asset Management Metadata Requirements with Facilities Data: *The initial stage involves a comprehensive identification of metadata requirements, now explicitly incorporating facilities data. This includes the types of facilities data to be captured, such as physical characteristics, usage patterns, maintenance records, and operational data, ensuring a detailed understanding of both AIM and facilities data for a holistic analysis approach.*

Establish Asset Management Metadata Standards for Facilities Data: *Following the definition of metadata requirements, the strategy progresses to establish standards that encompass facilities data. These standards ensure the structured, consistent capture and interoperability of facilities data within the metadata framework, based on industry practices and data modelling standards pertinent to facilities management.*

Implement Metadata Capture and Storage Processes for Facilities Data: *This stage delineates the processes for capturing and storing metadata, now with an emphasis on including facilities data. By integrating these*

Figure 3. Enhanced AIM Analysis with Facilities Data Integration

processes into existing asset management workflows or creating new ones, the strategy ensures the comprehensive documentation, version control, and reliability of metadata, including facilities data.

Integrate Facilities Data into the AIM Model: *The root of the strategy lies in integrating metadata, enriched with facilities data, into the AIM model. This involves associating detailed facilities data with relevant assets within the model, enhancing the AIM's analytical capabilities and providing a richer, data-driven understanding of asset performance and management needs.*

Establish Metadata Governance Including Facilities Data: *To maintain the integrity and quality of metadata, including facilities data, governance procedures are put in place. These include data quality checks specific to facilities data, ensuring its accuracy, consistency, and relevance within the AIM analysis.*

Utilize Facilities Data-Enriched Metadata in AIM Analysis: *Leveraging the enriched metadata for AIM analysis becomes pivotal, utilizing facilities data to enhance analytical depth. This includes using facilities data for asset management, predictive maintenance, performance analysis, and strategic decision-making, offering a comprehensive view of asset utilization and management.*

Update Facilities Data within Metadata as Needed: *Recognizing the evolving nature of facilities management, the strategy includes regular updates to metadata to incorporate new facilities data. This ensures the AIM model reflects the latest data, supporting dynamic asset management strategies.*

Train and Educate Stakeholders on Facilities Data Integration: *Training programs are expanded to cover the integration and management of facilities data within metadata. Stakeholders are educated on the significance of facilities data, its capture, storage, and utilization within the AIM framework, promoting informed asset management practices.*

Monitor and Improve the Strategy with Facilities Data Feedback: *Continuous monitoring and improvement of the strategy now include a focus on facilities data integration. Regular audits, stakeholder feedback, and reviews of facilities data integration practices guide the strategy's evolution, optimizing its effectiveness and efficiency in asset management.*

By weaving facilities data throughout the metadata integration strategy, the approach not only enriches the AIM analysis but also ensures a more nuanced, comprehensive understanding of asset management requirements, facilitating informed decision-making and operational excellence in asset management practices.

On this basis, effective data analysis and understanding of Asset Information Management (AIM) heavily rely on well-defined data types, formats, and levels of detail for analysis (Chen, et al., 2017). Establishing data standards is crucial to ensure consistency and accuracy in the structure, syntax, and semantics of metadata. To achieve this, organizations need to define and implement processes for capturing, storing, and documenting metadata across the AIM model. This involves associating metadata with relevant assets or elements within the model, enabling seamless data retrieval and analysis (Vnuk, Koronios and Gao, 2012).

Governance procedures play a pivotal role in maintaining the accuracy, consistency, and integrity of metadata (Guillen, et al., 2016). Regular reviews and updates of metadata become essential as new data becomes available or changes occur within the AIM framework. Leveraging metadata becomes paramount in filtering, sorting, searching, or aggregating data for AIM analysis, allowing organizations to extract valuable insights efficiently (Vnuk, Koronios and Gao, 2012).

To ensure successful implementation and maintenance of metadata practices, organizations must invest in training programs to raise awareness and knowledge among employees about metadata's significance. This empowers the workforce to understand the relevance of metadata and its impact on data analysis and decision-making processes. Continuous monitoring, evaluation, and optimization of the metadata strategy ensure its alignment with evolving business needs and technological advancements (Centre for International Governance Innovation, 2018). Henceforth, a well-structured strategy is crucial for the success of AIM data analysis aiming to have a better digital management of the asset. It involves defining data types, formats, and levels of detail, as well as establishing data standards, implementing robust processes, and maintaining governance procedures. By adopting such a strategy, organizations can effectively leverage metadata to enhance their AIM capabilities, leading to informed decision-making and sustainable growth. However, it is equally important to acknowledge and understand the limitations of this approach to ensure its effective implementation and avoid potential challenges in utilizing metadata for AIM analysis.

On this basis, the researcher created a heatmap provides a visual comparison, mapping each data issue to relevant strategic steps in asset management metadata. The presence of a '1' indicates the importance of addressing the specific data issue within the corresponding strategic step. This representation helps to understand where efforts should be focused to improve asset management metadata practices as per research's findings.

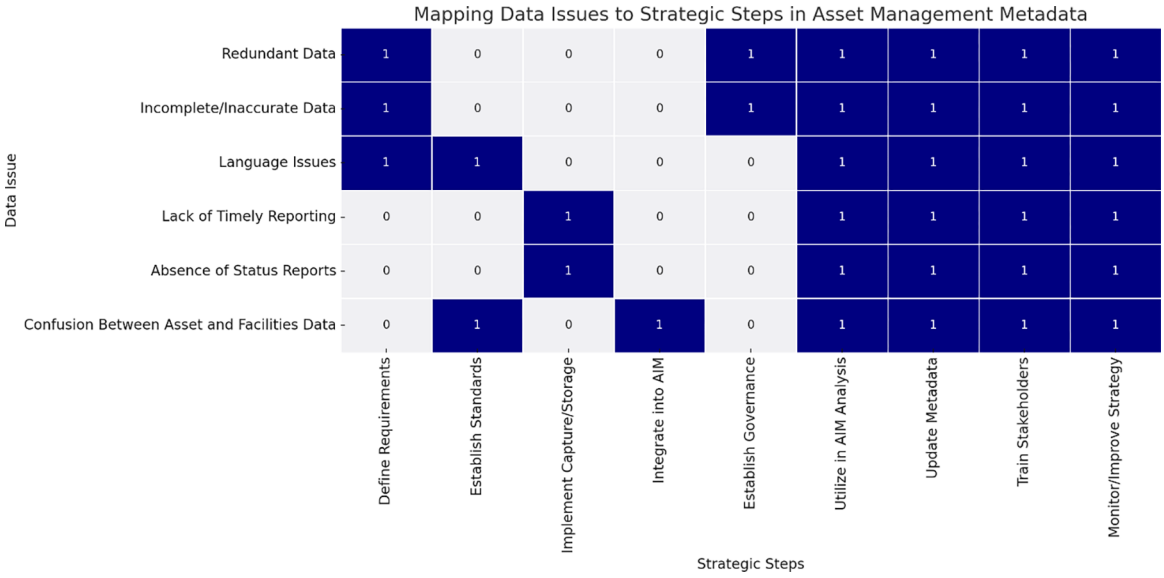

Figure 4. A heatmap between problems and the proposed strategy for Enhanced Asset Management

For instance, "Redundant Data" is crucial to address when defining requirements, establishing governance, and throughout the utilization, update, training, and monitoring phases. Similarly, "Incomplete/ Inaccurate Data" has been marked as critical across multiple strategic steps, emphasizing the need for thorough data quality management processes. This heatmap serves as a strategic tool for decision-makers, indicating the areas that require immediate attention and the steps that can mitigate the impact of each data issue on asset management. The potential limitations of implementing the proposed strategy, as identified from the literature review, could be summarized as follows:

Subjectivity and Interpretation: *The process of defining metadata requirements and establishing standards can be influenced by subjective decision-making and interpretations. According to Johnny and Trovati (2019), metadata definitions can vary among different stakeholders, leading to inconsistencies and discrepancies in data representation and analysis. This subjectivity can impact the accuracy and reliability of AIM analysis results.*

Implementation Challenges: *The implementation of metadata capture and storage processes can be complex, particularly for large and diverse datasets. According to Charles, et al., (2013), organizations often face challenges in integrating metadata into existing systems and databases, requiring additional efforts for data mapping and alignment. These implementation challenges may lead to delays and resource-intensive tasks.*

Data Volume and Complexity: *As data volume and complexity increase, maintaining accurate and up-to-date metadata becomes challenging SCIKIQ (2023). state that organizations dealing with vast amounts of data may struggle to keep metadata synchronized with real-time changes. The lack of updated metadata may hinder the accuracy of AIM analysis and decision-making processes that is critical.*

Governance and Enforcement: *While defining governance procedures for metadata accuracy and consistency is crucial, ensuring adherence to these procedures can be difficult. As noted by SCIKIQ (2023), organizations may encounter difficulties in enforcing governance policies across various departments and stakeholders, resulting in inconsistent metadata practices.*

Limited Stakeholder Awareness: *Despite implementing training programs, stakeholders may still lack a comprehensive understanding of metadata's importance and its impact on AIM analysis. However, it is suggested that insufficient stakeholder education can lead to underutilization of metadata capabilities, limiting the potential benefits it offers (Gartner, 2012).*

Resource Constraints: *Continuous monitoring and improvement of the metadata strategy require dedicated resources and expertise. Smaller organizations or those with limited budgets may face challenges in allocating sufficient resources for metadata management and optimization, as highlighted by (Gartner, 2012).*

Integration with Legacy Systems: *Organizations with legacy systems may struggle to integrate metadata practices seamlessly. According to Kitchin, Lauriault and McArdle (2015), retrofitting metadata requirements into existing systems may require significant modifications and investments, potentially leading to compatibility issues and delays.*

Scalability and Flexibility: *The metadata strategy should be scalable and flexible enough to accommodate future data requirements and evolving analysis goals. However, Xie, et al. (2021) suggests that achieving full scalability and flexibility can be challenging, especially when dealing with rapidly changing business needs and data sources.*

Data Privacy and Security: *The inclusion of metadata in AIM analysis raises data privacy and security concerns. As highlighted by Munier, et al. (2014), metadata may contain sensitive information that requires protection to prevent unauthorized access or potential misuse, necessitating robust data security measures.*

Addressing these limitations requires organizations to be proactive Kapogiannis, Fernando and Alkhard (2021) in formulating metadata governance policies, providing comprehensive training to stakeholders, and adopting advanced technologies for efficient metadata management and integration. Moreover, continuous research and innovation in metadata practices can lead to more effective solutions for overcoming these challenges in the context of advocating for a strategic integration of facilities data with Asset Information Modeling (AIM) and Digital Asset Management (DAM).

Conclusion

In conclusion, the research underscores the critical shift from traditional to digital asset and facilities management, advocating for a strategic integration of facilities data with Asset Information Modeling (AIM) and Digital Asset Management (DAM). This integrated approach emphasizes the crucial role of effective metadata management in enhancing AIM analyses and leveraging facilities data. By systematically defining metadata requirements, establishing comprehensive metadata standards, refining metadata capture and storage processes, integrating metadata into the AIM model, implementing stringent metadata governance, utilizing metadata to enrich AIM analysis, updating metadata to reflect current data, educating stakeholders on metadata's importance, and continuously refining the metadata strategy, organizations can significantly improve the precision, reliability, and consistency of their asset management efforts. This holistic strategy promises to improve decision-making processes in asset and facility management, thereby boosting operational efficiency and effectiveness. The successful application and ongoing research into this strategy are poised to make substantial contributions to advancing AIM analysis and optimizing metadata use, setting a new benchmark for asset management excellence in the dynamic landscape of the construction and infrastructure sectors.

Ethical Considerations

In this study conducted at a public school in the kingdom of Saudi Arabia, specific steps were undertaken to address ethical considerations while maintaining confidentiality. Due to privacy concerns, the school's name has been withheld, highlighting a commitment to protect its identity. Although the study deviates from the conventional research ethics procedures observed in many academic settings, ethical integrity has been insured through the acquisition of written permission from the department head. This approval process, albeit less formal than those seen with institutional review boards or ethics committees, serves as a crucial ethical safeguard. It reflects the adaptability and context-specific nature of ethical oversight in academic research, emphasizing the importance of institutional approval in ensuring responsible and respectful research conduct.

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