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The use of Computerized Maintenance Management Systems in Public Administration Buildings: a systematic literature review

A utilização de Sistemas Informatizados de Gestão de Manutenção em edificações da Administração Pública: revisão sistemática de literatura

El uso de Sistemas Informatizados de Gestión del Mantenimiento en Edificios de la Administración Pública: revisión sistemática de la literatura

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KEYWORDS
Construction 4.0. Public Management. Computerized Maintenance Management Systems.

Abstract: This study aims to identify computerized maintenance management systems (CMMS), their implementation stage, processes, functionalities and other integrated technologies in the maintenance of public administration buildings. The methodology used was a systematic literature review (SLR), divided into three stages: planning, execution and summarization. A total of 20 articles were selected from the Scopus and Science Direct databases. It was observed that CMMS are integrated with technologies such as BIM platforms, Augmented Reality, drones, smart sensors and digital twins, which optimizes maintenance management in public administration. Furthermore, SLR showed that developed countries, such as South Korea, England and Italy, are more advanced in the use of CMMS. In contrast, countries like Brazil and Kenya, although they utilize CMMS, do not take advantage of all available functionalities, typically using them to manage corrective maintenance, issue work orders and perform registrations. Additionally, it was identified that some CMMS are employed to manage specific building systems, such as air conditioning and elevators.

PALAVRAS-CHAVE
Construção 4.0. Gestão Pública. Sistemas Informatizados de Gestão de Manutenção.

Resumo: *Este estudo tem como objetivo identificar os sistemas informatizados de gestão de manutenção (CMMS), seu estágio de implantação, os processos, funcionalidades e demais tecnologias integradas na manutenção de edificações da administração pública. A metodologia utilizada foi a revisão sistemática da literatura (RSL), dividida em três etapas: planejamento, execução e sumarização. Foram selecionados 20 artigos nas bases de dados Scopus e Science Direct. Observou-se que os CMMS estão integrados a tecnologias como plataformas BIM, Realidade Aumentada, drones, sensores inteligentes e gêmeos digitais, o que otimiza a gestão da manutenção na administração pública. Além disso, a RSL mostrou que países desenvolvidos, como Coreia do Sul, Inglaterra e Itália, estão mais avançados no uso dos CMMS. Em contraste, países como Brasil e Quênia, embora utilizem CMMS, não aproveitam todas as funcionalidades disponíveis, sendo geralmente usados para gerenciar manutenções corretivas, emissão de ordens de serviço e realização de cadastros. Adicionalmente, foi identificado que alguns CMMS são empregados no gerenciamento de sistemas prediais específicos, como climatização e elevadores.*

PALABRAS CLAVE
Construcción 4.0. Gestión Pública. Sistemas Informatizados de Gestión del Mantenimiento.

Resumen:*Este estudio tiene como objetivo identificar los sistemas computarizados de gestión del mantenimiento (CMMS), su etapa de implementación, procesos, funcionalidades y otras tecnologías integradas en el mantenimiento de los edificios de la administración pública. La metodología utilizada fue la revisión sistemática de la literatura (RSL), dividida en tres etapas: planificación, ejecución y resumen. Se seleccionaron 20 artículos de las bases de datos Scopus y Science Direct. Se observó que los CMMS se integran con tecnologías como plataformas BIM, Realidad Aumentada, drones, sensores inteligentes y gemelos digitales, lo que optimiza la gestión del mantenimiento en la administración pública. Además, RSL demostró que los países desarrollados, como Corea del Sur, Inglaterra e Italia, están más avanzados en el uso de CMMS. En cambio, países como Brasil y Kenia, aunque utilizan CMMS, no aprovechan todas las funcionalidades disponibles, utilizándose generalmente para gestionar mantenimientos correctivos, emitir órdenes de trabajo y realizar registros. Además, se identificó que algunas CMMS se utilizan para gestionar sistemas específicos del edificio, como aire acondicionado y ascensores.*

Introduction

Since ancient civilizations, sedentary humans developed construction activities, initially just for shelter, and later expanded the functionalities of built spaces (Gonçalves et al., 2021). Over the years, construction methods and techniques have been refined (Patriota Jr., Batista & Póvoas, 2020). Currently, the market is becoming increasingly aware of the need to apply technological innovations within organizations, aiming to provide greater dynamism, reduce time and costs, and increase efficiency and effectiveness through the use of new methods and tools for the rationalization and standardization of construction processes (Page et al., 2020; Silva, 2022).

In the contemporary context, this dynamic is linked to the search for a product capable of meeting the demands and functions of buildings and their users, whether they be for work, industrial, residential, or governmental purposes (Gonçalves et al., 2021; Santos, Alves & Pinheiro, 2021; Silva, 2022). Thus, it is understood that a building must effectively ensure durability and functionality throughout its entire life cycle. For this, building maintenance activities are essential for constructions (Viana et al., 2022).

The focus on the need for the preservation of buildings is longstanding and has been recorded with particular importance throughout history. For example, in the Roman Empire, there was the figure of the aedile, the title for the ancient magistrates responsible for inspecting and managing the conservation and maintenance of public buildings (Mendes et al., 2022).

According to NBR 5674, building maintenance is an important tool for maintaining the functionality and habitability of buildings and can be characterized as any intervention performed on the building and its constituent parts, with the aim of conserving or restoring its functional capacity (ABNT, 2012; Mendes et al., 2022).

In the realm of buildings managed by public services, it is very common to observe pathological manifestations, which may originate, among other reasons, from a lack of maintenance services or from inadequate actions (Viana et al., 2022). To prevent these defects, the sectors responsible for the conservation, cleaning, and maintenance services of the building are required to implement a maintenance management system (BRASIL, 2020). Thus, it is necessary to have a maturity model for building maintenance teams regarding the execution of good maintenance practices (Khalid et al., 2019; Viana et al., 2022).

However, it is observed that despite guidelines on the subject, many public buildings face problems stemming from inadequate maintenance. In this regard, the main deficiencies in maintenance management have been: lack of a building maintenance plan, absence of preventive maintenance, an excess of corrective maintenance, a shortage of trained or specialized personnel, insufficient budgets and/or material resources, low quality of services performed, deficiencies in project design, and bureaucratic hurdles during the bidding process (Viana et al., 2022).

Nevertheless, according to studies conducted by Shrestha, Shrestha & Kandie (2014) in Kenya and Kalumbu, Mutingi & Mbohwa (2016) in Namibia, these deficiencies tend to be mitigated when management shifts from analog to computerized maintenance management. Silva (2022) emphasizes that the pursuit of process improvements and technological innovations, new tools, and methodologies, such as facilities management and computerized maintenance management systems (CMMS), are increasingly being applied in both private organizations and public administration.

A CMMS, or Computerized Maintenance Management System, is a software solution designed to streamline building maintenance processes and improve asset management within organizations. It allows maintenance managers to efficiently schedule, track, and analyze the entire workflow involved, including work orders, inventory, maintenance tasks, budgets, and more. By using a CMMS, organizations can reduce downtime, extend the lifespan of building systems, machines, and equipment, optimize labor resources, and enhance overall maintenance operations (Bleasdale et al., 2022).

In this regard, the present study aims to conduct a systematic literature review to understand which CMMS are being used

worldwide, what types of maintenance and implementation stages are integrated into CMMS, which processes/functions are applicable in the use of CMMS, and what other technologies are integrated with CMMS.

Methodological elements of the research

The Systematic Literature Review (SLR) was based on Keele et al. (2007), who define SLR as a secondary study that seeks to identify, evaluate, and extract interpretations through the analysis of primary studies, delimited by a research area or phenomenon of interest. It aims to classify, analyze, and elucidate relevant, available studies that provide answers to the research questions.

The SLR is developed in stages, structuring the research work in a parameterized way. In the planning stage, a research protocol is developed, followed by the execution stage, which involves searching and selecting studies. The third stage, summarization, consists of processing and analyzing the data, demonstrating and reporting the state of the art of the subject under study.

The SLR aimed to investigate studies on the use of computerized systems in the management of building maintenance. For this, the following research questions were defined:

- Which computerized maintenance management systems were identified in the literature?
- What types of maintenance and implementation stages of computerized maintenance management systems were identified in the literature?
- What processes/functions are applicable in the use of computerized systems for maintenance management in buildings belonging to public institutions?
- What other technologies integrated with computerized maintenance management systems were identified in the literature?

According to Page et al. (2021), the research protocol is the product of the SLR planning stage, in which the necessary information for conducting the systematic review is specified.

To define the search terms, the PICo strategy was used (Akobeng, 2005), which helps define the search terms based on the research questions by extracting the Population (P), Interest (I), and Context (Co). The terms defined were: Computerized maintenance management system (CMMS); Computerized system; Public service; Government; Building maintenance; Maintenance issue.

The search string was then defined by combining the search terms (and synonyms) with the Boolean operators "AND" and "OR" to be used in the search databases, resulting in the following string: (“computerized maintenance management system” OR “CMMS” OR “computerized system”) AND (“public service” OR “government”) AND (“building maintenance” OR “maintenance issue”).

The databases Science Direct, Scopus, ASCE, and Web of Science were chosen as they contain a large technical and scientific collection internationally, and therefore, could return a significant number of publications in the initial search.

Sources that yielded insignificant results in the initial search (n<20) were excluded, as well as databases where it was not possible to apply the filters due to the limitations outlined in the protocol.

The inclusion or exclusion criteria for the selection of articles were:

- Articles in Portuguese, English, and Spanish were included (Inclusion Criterion – IC1);
- Articles containing the search terms in the title, abstract, and keywords were included (Inclusion Criterion – IC2);
- Articles from the Architecture, Engineering, and Construction (AEC) sector were included (Inclusion Criterion – IC3);
- Duplicate articles were excluded (Exclusion Criterion – EC1);
- Articles that do not address computerized systems and building maintenance management were excluded (Exclusion Criterion – EC2);
- Articles that do not present an analysis methodology were excluded (Exclusion Criterion – EC3);

• Systematic review articles were excluded (Exclusion Criterion – EC4).

During the research, journal articles, book chapters, and conference papers were included. By using the filters available in the databases, it was also possible to restrict the language of the studies and the target period from 2013 to 2023 (the last 10 years) according to the protocol. After generating the export file of the results, it was possible to consolidate them into a reference management tool in this case, the online software Rayyan was used to tabulate the data and organize and conduct the selection phase.

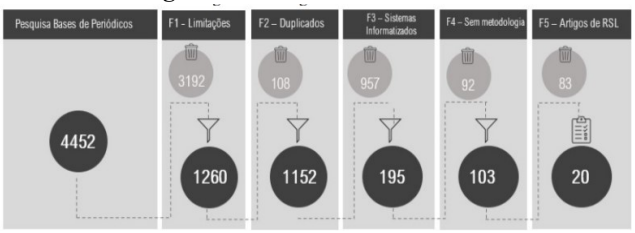
In the eligibility phase, using Rayyan's filter tools, duplicate articles were excluded (EC1); by reading the title and abstract, studies that did not address computerized systems and building maintenance management were excluded (EC2), as well as those that did not present an analysis methodology (EC3); and through reading the full articles, studies that only provided a systematic literature review were excluded (EC4). After this phase, the remaining articles were included for quantitative and qualitative synthesis.

As determined in the research protocol, databases that did not meet the pre-defined criteria were disregarded. Thus, the Scopus and Web of Science databases were excluded, as they returned an insignificant number of studies in the initial search (n = 8) and (n = 3), respectively. As a result, the remaining databases were Science Direct, with 2,447 studies, and Scopus, with 2,005 studies, totaling 4,452 studies for the selection phase

In the next stage, the limitations determined by the protocol were applied using the databases' own tools. As a result, 3,192 articles were excluded based on these limitations: 1,806 were excluded for not being "journal articles," "book chapters," or "conference papers"; 989 were excluded for not belonging to the broad field of "Engineering"; and 397 were outside the study period (2013-2023), resulting in 1,260 studies for the eligibility phase.

Next, during the eligibility phase, the titles and abstracts were read, and exclusion criteria were applied. In this phase, 1,212 articles were excluded: 108 of them were duplicates (EC1); 957 studies were excluded for not addressing computerized systems and building maintenance management (EC2). After the full reading of the articles, 92 were excluded for not presenting an analysis methodology (EC3), and 83 studies were excluded for being systematic reviews (EC4), resulting in 20 studies eligible for qualitative synthesis.

Figure 1
SLR Flow Diagram



Source: Prisma (2020) – Adapted by the authors

To compose the report of this SLR, the PRISMA Flow Diagram for systematic literature review was used (PRISMA, 2020), as shown in Figure 01.

Presentation and discussion of results

Quantitative results

Table 01 presents the list of the 20 selected articles, organized in ascending order by year of publication (from oldest to most recent). The compilation includes the year, author, title of the work, and citations, which were extracted from Google Scholar on June 8, 2023. The article "Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus" (Qiuchen Lu et al., 2020) was the most cited, with 223 citations. The second most cited was "The Computerized Maintenance Management System: An Essential Tool for World-Class Maintenance" (Wienker, Henderson & Volkerts, 2016), with 118 citations, followed by "Business Processes Improvement on Maintenance Management: A Case Study" (Abreu et al., 2013) with 53 citations.

Table 1
Portfolio of Selected Articles

YEAR	AUTHOR	TITLE	JOURNAL	CITATIONS
2013	Abreuet al.	Business Processes Improvement on Maintenance Management: a Case Study	Procedia Technology	53
2014	Shrestha; Shrestha; Kandie	A Road Maintenance Management Tool for Rural Roads in Kenya	Construction Research Congress	5
2014	Fouchal; Hassan; Firth	Maintenance, Retrofit and Operation Decision Support Tool for Both Domestic and Non-domestic Buildings	International Conference on Computing in Civil and Building Engineering	5
2015	Handokoet al.	Building an In-House CMMS to Simplify Maintenance Management in an Oil and Gas Company	OnePetro	2
2016	Kalumbu; Mutingi; Mbohwa (2016)	Critical Success Factors for Developing Building Maintenance Strategies: A Case of Namibia	International Conference on Industrial Engineering and Engineering Management	11
2016	Wienker; Henderson; Volkerts	The computerized maintenance management system an essential tool for world class maintenance	Procedia Engineering	118
2016	Jiang et al.	Application of Discrete-Event Simulation in the Quantitative Evaluation of Information Systems in Infrastructure Maintenance Management Processes	Journal of Management in Engineering	6
2016	Kim; Yu	Improvement of Facility Condition Assessment Processes Using BIM Data	Construction Research Congress	6
2017	Senra; Lopes; Oliveira	Supporting maintenance scheduling: a case study	Procedia Manufacturing	20
2017	Mazieri; Quinto Jr.	Comparison of Environmental Assessment Methods, LEED for Schools, and AQUA-HQE, Applied in Brazilian Public Schools, from the Perspective of Post-Occupation and Maintenance	International Conference on Sustainable Infrastructure	1
2018	Fuller et al.	Performance-Based Maintenance Contracting in Florida: Evaluation by Surveys, Statistics, and Content Analysis	Journal of Construction Engineering and Management	7
2018	Moreira; Ruschel; Behzadan	Building Owner Manual Assisted by Augmented Reality: A Case from Brazil	Construction Research Congress	5
2019	Morais; Lordsleem Jr.	Building maintenance management activities in a public institution	Engineering, Construction and Architectural Management	16

YEAR	AUTHOR	TITLE	JOURNAL	CITATIONS
2019	Accorsi et al.	A tailored Maintenance Management System to control spare parts life cycle	Procedia Manufacturing	14
2020	Qiuchen Lu et al.	Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus	Journal of Management in Engineering	223
2020	Assaf; Awada; Srour	Driven Approach to Forecast Building Occupant Complaints	Construction Research Congress	2
2021	Johannes et al.	Identifying Maturity Dimensions for Smart Maintenance Management of Constructed Assets: A Multiple Case Study	Journal of construction engineering and management	14
2022	Tanet al.	Streamlining WELL Concepts of Office Buildings for Developing Countries: The Case of Malaysia	Construction Research Congress	3
2022	Baird; Joly	How Can I Convince Finance to Fund My Asset Management Program?	Pipelines 2022	0
2022	Bleasdaleet al	Inspection and Maintenance of Ferry Terminals: Risk Reduction and Cost Efficiency	Ports 2022	0

Source: Authors.

Regarding the distribution of articles over the selected period, there is a predominance of studies in the years 2016 and 2022. The country with the highest number of publications is Brazil (3 publications), followed by the USA, England, and Italy (2 publications each). The remaining countries have only 1 publication, as shown in Figure 02. It is important to note that the country identified in this analysis was determined by the location where the research or case study was conducted.

Figure 2
Distribution of the Number of Publications by Year and Country of the Research

Ano	Alemanha	Brasil	Canadá	China	Coreia do Sul	EUA	Holanda	Indonésia	Inglaterra	Itália	Libano	Malásia	Namíbia	Portugal	Quênia	Total
2013														1		1
2014									1						1	2
2015								1								1
2016	1			1	1								1			4
2017		1								1						2
2018		1				1										2
2019		1								1						2
2020									1		1					2
2021							1									1
2022			1			1						1				3
2023																0
Total	1	3	1	1	1	2	1	1	2	2	1	1	1	1	1	20

Source: Authors

Figure 3
Distribution of the Number of Publications by Journals

Periódico	Publicações
Construction Research Congress	5
Engineering, Construction and Architectural Management	1
International Conference on Computing in Civil and Building Engineering	1
International Conference on Industrial Engineering and Engineering Management	1
International Conference on Sustainable Infrastructure	1
Journal of Construction Engineering and Management	2
Journal of Management in Engineering	2
OnePetro	1
Pipelines 2022	1
Ports 2022	1
Procedia Engineering	1
Procedia Manufacturing	2
Procedia Technology	1
Total	20

Source: Authors

Among the analyzed journals, the "Construction Research Congress" stands out with five publications, followed by the "Journal of Construction Engineering and Management," "Journal of Management in Engineering," and "Procedia Manufacturing," each with two publications. The other journals each had one publication, as shown in Figure 03.

In the selected studies, a thematic trend was observed, showing that over the past 10 years,

research on computerized maintenance management systems (CMMS) has mainly focused on corrective maintenance, with few authors including both preventive and corrective maintenance. Additionally, the authors highlight the need to implement CMMS that integrate BIM and Digital Twin through algorithms. Contract management and acquisition through public tenders were also identified as key themes. Finally, there was a predominance of CMMS related to the management of elevator maintenance and HVAC systems, as shown in Figure 04.

Figure 04
Word Cloud – SLR

Source: Authors

Qualitative results

To this end, the summary of the contributions of the studies is presented chronologically below.

The study conducted by Abreu et al. (2013) presented a case study on the implementation of a maintenance management system at ANA Airports in Portugal. This allowed for an understanding of the business process model related to maintenance, covering infrastructures, systems, and equipment, as well as the organizational structure of the different departments. The study pointed out that computerized management should include five main structures: maintenance management; operational management (specifies the process of recording related activities such as corrective maintenance, preventive maintenance, and technical services); project management (a repository of new and ongoing projects related to maintenance and investments, where all activities are recorded, including contract specifications); CMMS management (responsible for the evolution and development of the information system); and knowledge management (ensures the sustainability of all business processes associated with the framework, a repository for all technical documentation, skills, and training acquired throughout the implementation of the CMMS).

The case study conducted by Shrestha, Shrestha & Kandie (2014) demonstrates the road maintenance management model in Kenya, which incorporates a CMMS that includes corrective maintenance, preventive maintenance, and extreme cases of rehabilitation of special structures (culverts and bridges). The software, known as the Road Maintenance Management System (RMMS), is managed by public administration engineers, who, upon detecting the need for maintenance, tender the works at the lowest price. The software is capable of tracking change requests across all activities in the work plan and thoroughly recording the progress of the construction.

The studies by Fouchal, Hassan & Firth (2014) present the early results of a project co-funded by the European Commission, Information Society, and Media Directorate-General. The article introduced software with new decision support tools to assist in providing personalized advice for buildings, using a combination of BIM data, monitoring technologies such as smart sensors, and performance-based analysis, user behavior, and expert knowledge to support decision-making for maintenance, retrofitting, and operation.

The studies conducted by a renowned university in Indonesia by Handoko et al. (2015) consider cost and time as crucial factors for the implementation of a computerized system in the oil and gas industry. In this regard, there are two alternatives to obtain a CMMS: in-house development or purchasing an off-the-shelf software package, with both options having their own sets of advantages and disadvantages. In this

particular case, the choice was to develop a proprietary CMMS, the INTRAMAS software. During the system implementation process, the study emphasizes the need to shift paradigms from a manual approach to a computerized approach, driven by the reluctance of the professionals involved due to a lack of computer skills.

The study conducted by Kalumbu, Mutingi & Mbohwa (2016) in Namibia concluded that the successful management of building maintenance in local governments depends on factors including the ability to respond to maintenance incidents, availability of funds to maintain buildings, quality of maintenance services, general health and safety measures for maintenance staff and building users, customer satisfaction, and availability of maintenance parts and components. The study also noted that computerized systems need to shift their focus from corrective maintenance to preventive maintenance. Additionally, it diagnosed that the current maintenance planning needs improvement to meet both short- and long-term building maintenance needs. There is also a great need to implement CMMS to handle functionalities such as data analysis, complaint tracking, and workforce distribution, which could result in significant savings of money and time. This would also improve maintenance reporting and provide feedback to both internal and external clients.

Regarding elevator maintenance, a study conducted in Germany by Wienker, Henderson & Volkerts (2016) highlights the deficiencies in the functionalities of current CMMS, which are used merely as a "work order system," lacking the ability to analyze and generate reports. The study concludes that an organization's IT infrastructure is a critical, and often underestimated, step in the implementation process of a CMMS. For the successful integration of a "new" tool, the speed and capacity of the infrastructure need to be ensured.

The study conducted by Jiang et al. (2016) at a metropolitan subway company located in Guangdong province (China) presents a framework for evaluating a computerized system in both functional and non-functional aspects at the maintenance management process level. The criteria consist of the following: (1) task suitability (i.e., users can apply the system to perform their work tasks without additional workload), (2) self-descriptiveness of the system (i.e., users can understand the functions of each module and various types of information, such as feedback information, warning information, etc.), (3) controllability (i.e., the ease of navigating and transitioning between different pages), (4) conformity with user expectations (i.e., the consistency of the functions of each module and the information displayed with user expectations), (5) error tolerance (i.e., how easily users can correct or handle faulty operations), (6) individualization (i.e., the alignment between system design and user habits), and (7) ease of learning (i.e., how easily users can learn to operate the system). A case study was conducted using this framework, and the results revealed that the system is positively associated with maintenance performance. The effects of the system at various levels in different processes and for different users were determined based on the functions within the organization. Furthermore, obstacles that hinder favorable user experiences with the system were identified. The case study confirms that the system's effects on maintenance performance can be quantitatively and objectively assessed through the application of the framework. Decision-makers can apply the framework during the planning phase of the system or in the optimization of an existing system.

The study by Kim & Yu (2016) in Seoul (South Korea) presents a BIM-based condition assessment approach that considers data interoperability through four main steps [1) condition assessment planning, 2) inspection/measurement, 3) priority analysis, and 4) response/update], with four key algorithms [1) BIM attributes and FM requirements mapping algorithm, 2) condition-related indicator algorithm, 3) BIM-based priority analysis algorithm, and 4) building model update algorithm]. The proposed approach allows facility

managers responsible for component conditions to use a BIM-based model directly in the facility management system without the need for additional manual data entry. This ensures that the necessary data input for facility management is more accurate and reliable through a computerized data management approach.

A study conducted in Italy by Senra, Lopes & Oliveira (2017) concluded that computerized maintenance management systems must include functionalities such as quick scheduling, taking into account equipment and technician availability, maintenance task processing times, due dates, and required skill levels. The study also developed an algorithm that supports the scheduling tool, consisting of availability time identification, a sorting method, and an assignment method, aimed at minimizing total delay.

A study conducted in public schools in Brazil by Mazieri & Quinto Jr. (2017) presents a reflection on the environmental assessment systems, LEED for Schools and AQUA-HQE, applied to two public school buildings in the southeastern region of Brazil. The public buildings evaluated were pioneers in these systems and, until 2017, are the only public school buildings certified in the country. The research assessed the post-occupancy management of these buildings, highlighting the importance of reducing environmental impacts during this earlier period of the building life cycle. It concluded that although materials and techniques are provided to reduce costs and facilitate maintenance of these buildings, environmental quality can be maintained by performing the necessary maintenance.

In Florida (USA), a study conducted by Fuller et al. (2018) proposes a maintenance management model based on service performance, through contracts that share risks between public administration and construction companies, based on a well-defined scope and quantifiable performance measures. The study highlights the various advantages of this system compared to more traditional contracts, including greater cost certainty, cost savings, easier asset management, partnership potential, risk transfer, greater capacity for innovation, simpler budgeting, reduced client staff, and the ability to perform life-cycle cost analyses.

In Brazil, an embryonic study highlighted the benefits of using augmented reality (AR) to assist in the building maintenance phase by reconciling textual information found in building owner manuals, which were transformed into graphical information. The authors Moreira, Ruschel, and Behzadan (2018) developed a prototype of an augmented reality application (LAR) through graphic software and a gaming platform, which can be launched on tablets and smart glasses. The study focused solely on applications in bathrooms, showcasing a step-by-step AR animation of a maintenance task for the user.

According to Morais & Lordsleem Júnior (2019), when analyzing the maintenance management of a public institution belonging to the Judiciary Power of the State of Pernambuco (Brazil), it was observed that the computerized system focuses only on corrective maintenance, with an average response rate of 86% for received requests. The highest demands are related to refrigeration, electrical, and plumbing installations, which account for 55% of the total requests. To improve the efficiency of maintenance management, the authors suggested enhancements to the functionality of the computerized system, such as: generating reports on the current state of the buildings of each institution, listing pending request types and all services performed in chronological order; simulating the amount of resources needed to raise or maintain the performance level of the building; generating reports estimating the costs incurred in maintenance activities; issuing alerts regarding the need for periodic maintenance in a building, according to the preventive maintenance plan; and prioritizing actions based on the risk level that the reported problems could pose to the professionals working in the building.

The study conducted in Italy by Accorsi et al. (2019) on the maintenance process of

electromechanical equipment (such as air conditioning systems and elevators) points out flaws in CMMS for failing to understand the various phases of the product life cycle, as well as not incorporating functionalities related to predictive maintenance. Thus, the study proposes a CMMS that supports coordination among groups of engineers and professionals through graphical user interfaces (GUIs) and performance metrics, such as cost and reliability, leading to informed decision-making from the design phase to the planning of maintenance tasks throughout the product's life cycle.

The research by Assaf, Awada & Srour (2020) presented a data analysis framework that employs text mining techniques and machine learning (NARX model) to help facility managers better understand and predict occupant complaints in a building. The framework was tested over a year using highly unstructured and unsolicited complaint data recorded by facility management operators in a residential complex located in Beirut (Lebanon). The results from the text mining indicated that air conditioning (AC) complaints are among the most frequent in the dataset studied. The use of the Nonlinear Autoregressive Exogenous (NARX) forecasting model developed to predict such complaints yielded acceptable validation and mean squared errors of 0.822 and 0.188, respectively. Ongoing work aims to expand this framework to include a larger dataset and develop a staffing plan to address these complaints, thereby increasing occupant satisfaction and building performance.

According to Qiuchen Lu et al. (2020), building maintenance management should incorporate the concept of multilayered architectures, thus encompassing asset management, maintenance, and operations through a digital twin (Digital Twin - DT). In this context, the study focused on presenting insights into the new field of dynamic DTs at the building and city levels. Additionally, the authors demonstrated the impact of digital modeling and performance analysis of infrastructure on organizational productivity and provided a foundation for optimizing city services, such as energy, waste, and transportation, as well as understanding the impact on broader social and economic relationships.

Through multiple case studies conducted in Amsterdam (Netherlands), Johannes et al. (2021) identified the maturity dimension indicators for building maintenance management, which are: governance structure (centralized or decentralized); location and detailing (absent, basic, or advanced); data-driven decision-making (absent, basic, or advanced); sustainability monitoring (basic or advanced); knowledge management (personal or organizational learning); culture (bureaucratic or entrepreneurial); and leadership (autocratic or collaborative). The authors conclude that maintenance organizations distinguish data requirements for maintenance engineering and maintenance management and should implement monitoring and tracking strategies for both requirements. They also point out that although maintenance managers may have outsourced maintenance execution to contractors, they may be reluctant to take responsibility for maintenance engineering data that, in the short term, seem relevant only to contractors.

The case study conducted by Tan et al. (2022) in Malaysia identified thirteen WELL concepts to support the health, well-being, and productivity of occupants in office buildings in a developing country. Ten of the identified concepts are consistent with the US WELL building standards: Air, Water, Nutrition, Light, Movement, Thermal Comfort, Sound, Materials, Mind, and Community. Three new concepts were established from this research in the context of Malaysia: Safety and Security, Construction and Maintenance Services, and IT Infrastructure.

In the USA, the authors Baird & Joly (2022) present software capable of automating information related to the available financial resources and the needs described in the maintenance plan for buildings. Thus, the tool is directly linked to cash flow management (current revenue used to pay for operations and maintenance), which in turn affects various

financial metrics, such as available operating cash and the debt service coverage ratio.

Finally, the study conducted at bus terminals in Canada by Bleasdale et al. (2022) presents a CMMS developed to consolidate existing methods and systems for asset management into a practical system, which included matrices such as: Finance, Terminal Development, Planning and Capital Projects, Terminal Maintenance, Standards, Internal Audit, Supply Chain, and Security. The long-term vision is to use condition assessment data, along with Long-Term Maintenance Plans, to develop a dashboard indicating the integrity of assets across all 47 marine terminals, aiming to focus maintenance efforts and facilitate infrastructure renewal planning.

Final considerations

All sectors of the construction industry are directly linked to regional and national socioeconomic development. However, it is necessary to adapt production processes to the principles and pillars of Construction 4.0, which are the products of the Fourth Industrial Revolution, responsible for causing positive impacts on the construction industry, particularly with the emergence of technologies that focus on key points such as the use of big data, artificial intelligence, robotics, simulation, the Internet of Things (IoT), cybersecurity, cloud computing, additive manufacturing, integration systems, and augmented reality.

The Systematic Literature Review (SLR) highlighted the technological advancements impacting the maintenance activities of buildings. Computerized Maintenance Management Systems (CMMS) integrate with technologies such as BIM, Augmented Reality (AR), Drones, Smart Sensors, and Digital Twins. This integration can optimize maintenance management by public administration. The SLR also showed that developed countries have a better adaptation to technological innovations, particularly in the USA, Canada, Germany, South Korea, England, and Italy. However, there are countries that, even while using CMMS, have not fully utilized all available resources. Examples include Brazil and the Republic of Kenya, where research indicated that CMMS are only used to manage corrective maintenance, issue work orders, and perform registrations. Another important factor is that often some CMMS are not used to manage the maintenance of entire buildings. HVAC systems and elevators have received more attention than other building systems, machinery, and equipment.

The range of applications of new technologies enables increased efficiency and productivity in this sector, which reduces the risk of errors, failures, and shortcomings by maintenance managers. The use of computerized technologies plays a fundamental role in the building maintenance management process, bringing a series of benefits and significant improvements, such as: Asset Management, Remote Monitoring, Sensors and connected devices that allow real-time remote monitoring, Scheduling and Prioritization, History and Documentation, Integration with Other Systems, and Data-Driven Decision Making.

That said, the integration of computerized technologies in the building maintenance management process in public institutions not only increases operational efficiency and transparency but also contributes to more effective use of public resources and the improvement of services provided to the population.

In this regard, it is recommended that the research be continued, suggesting the conduction of a comparative study between public buildings that use computerized management and those that use analog management, and, based on indicators, develop a technical-economic feasibility study of the two management formats.

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