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Proposal for integrating drone images and BIM in educational public buildings to support maintenance management

Propuesta de integración de imágenes de drones y BIM para apoyar la gestión de mantenimiento en edificios educativos públicos

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Abstract

Educational public buildings face challenges in the maintenance management (MM) of their envelopes due to the need for more information about the built asset and the absence of standardized and transparent processes. This study proposes a preliminary method to integrate drone images and BIM to support the MM of educational public buildings with low digital maturity. This investigation adopted a case study approach. The main stages involved a Systematic Literature Review (SLR) and a Case Study in a public university, including inspections of ten buildings and a questionnaire administered to the MM team. The SLR revealed a need for studies in contexts with low digital maturity, emphasizing using expensive and complex tools. The case study identified maintenance failures and the need for clear guidelines. Interviews confirmed the need for a preventive culture and a shortage of skilled labor. These insights supported the preliminary proposal for integrating drone images and BIM in educational buildings to support maintenance management. The following steps include implementing and evaluating the process in two case studies to improve transparency and efficiency in MM.

Keywords: Building maintenance; Inspection; Drone; Building Information Modeling (BIM).

Resumen

Los edificios educativos públicos enfrentan desafíos en la gestión de mantenimiento (GM) de sus envolventes debido a la falta de información sobre el activo construido y a la ausencia de procesos estandarizados y transparentes. Este estudio propone un método preliminar para integrar imágenes de drones y BIM para apoyar la GM de edificios educativos públicos con baja madurez digital. La investigación adoptó un enfoque de estudio de caso. Las principales etapas incluyeron una Revisión Sistemática de la Literatura (RSL) y un Estudio de Caso en una universidad pública, incluyendo inspecciones de diez edificios y un cuestionario administrado al equipo de GM. La RSL reveló la necesidad de estudios en contextos con baja madurez digital, destacando el uso de herramientas costosas y complejas. El estudio de caso identificó fallas en el mantenimiento y la necesidad de pautas claras. Las entrevistas confirmaron la necesidad de una cultura preventiva y la falta de mano de obra calificada. Estos hallazgos respaldaron la propuesta preliminar para integrar imágenes de drones y BIM en edificios educativos para apoyar la gestión de mantenimiento. Los siguientes pasos incluyen la implementación y evaluación del proceso en dos estudios de caso para mejorar la transparencia y eficiencia en la GM.

Palabras Clave: Mantenimiento de edificios; Inspección; Dron; Modelado de Información de Construcción (BIM).

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1. Introduction

During construction, uncontrolled resources impact project performance. Earned Value Management (EVM) is a widespread method used for Buildings that are continuously exposed to actions that overcome their components during use. Building envelope systems, such as roofs and façades, undergo even more severe degradation processes, as they are directly exposed to weather conditions and serve as interfaces with the surrounding environment (Madureira et al., 2017). The actions affecting these envelopes can have various origins, including physical, chemical, mechanical, and biological (Gaspar and Brito, 2008). (Bauer, 2020) explains that the impact of these actions can weaken the resistance of coating layers, leading to system failures and a loss of building performance.

It is estimated that maintenance costs for a 50-year-old building can represent about 75 to 80% of the total expenses (Hauashdh et al., 2022). With the increasing number of aging buildings worldwide, maintenance operations have become a crucial issue on a global scale (Islam et al., 2021). (Hauashdh et al., 2022) warn of the significant cost increase when ineffective maintenance is carried out, requiring more complex interventions. Additionally, (Salzano et al., 2023) point out that maintenance management (MM) of buildings during the Operation and Maintenance (O&M) phase represents the costliest activity throughout the life cycle, accounting for 60% of total expenses. Given this percentage, the importance of this activity is evident.

According to (Chua et al., 2018), implementing proper maintenance management (MM) for buildings requires considering factors such as documentation and project management, organization and planning of activities, establishing standard procedures, cost management, and sustainability actions. (Au-Yong et al., 2019) Emphasize that the importance of financial and time factors reinforces the need for careful planning and attention to maintenance activities. Although numerous studies discuss the impacts of MM on buildings, (Islam et al., 2021) state that the current global construction scenario is still primarily made up of buildings that either need more maintenance or have poor maintenance, regardless of their age. (Büron, 2018) notes that Brazil faces a similar situation, with buildings lacking or inadequate maintenance. This highlights the need for awareness among managers and owners to prevent accidents and preserve assets.

Specifically in the Brazilian context, public buildings are often neglected in maintenance, leading to numerous structures in poor condition and abandonment (Silveira da Costa et al., 2022). Furthermore, regarding public buildings in Brazil, aspects related to service provision laws must be considered, whether through internal teams or external hiring via public tenders (Tribunal D.C.D.U, 2014). Therefore, managers must deeply understand the technical aspects, legislation, and administrative procedures (Da Fontoura et al., 2020). Buildings of public educational institutions present even greater complexity, encompassing facilities for various activities and composed of different types of buildings that require specific care (Moreno et al., 2022).

Despite the challenges, Brazilian laws establish guidelines to ensure building performance. Several standards guide maintenance, such as NBR 5674 (ABNT, 2024c) for maintenance system organization, NBR 14037 (ABNT, 2024a) for maintenance operations, NBR 15575 (ABNT, 2024b) focusing on residential performance, and NBR 16280 (ABNT, 2024d) for renovations. NBR 5462 (ABNT, 1994) defines maintenance as technical and administrative activities to preserve an item's integrity, while NBR 16747 (ABNT, 2020) addresses the performance of building systems throughout their lifespan.

On the other hand, technology is a crucial issue in building maintenance management (MM). Drones, for instance, can swiftly gather information about the current state of buildings (Silva et al., 2024), providing an enormous amount of data for processing and analysis. Building Information Modeling (BIM) is another powerful tool, enhancing MM by providing material and spatial data, reports, and technical analyses or as an interface for a repository that enables data acquisition, monitoring, processing, and transformation (Volk et al., 2014). Integrating visual assets collected by drones with BIM models is a promising development that can significantly support MM.

Therefore, the literature shows several studies considering the integration focuses on the development of methods for automatic damage detection (Tan et al., 2024); (Gan et al., 2023); (Tan et al., 2022); (Xu and Turkan, 2020); (Solla et al., 2020); (Ribeiro et al., 2020); (Serrat et al., 2020). These studies incorporate complex and expensive technologies, such as laser scanners. At the same time, some other studies focus on manual processes for detecting and integrating visual data related to pathological manifestations into BIM without relying on image processing

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Vol. 39
Nº3 2024
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algorithms (Jofré-Briceño et al., 2021); (Rodrigues et al., 2023); (Matos et al., 2023). However, there is still a lack of applicable methods for anomaly detection and integration of these visual assets into BIM to support building maintenance management.

This study proposes a preliminary method for integrating drones and BIM to support the maintenance management (MM) of building envelopes in educational public buildings with limited digital tools and processes. To achieve that, a state-of-the-art review was conducted through a Systematic Literature Review, aiming to understand how the scientific community has been integrating drones with Building Information Modeling (BIM) to support maintenance management. Also, a case study involving inspections of 10 buildings at a public educational institution, analysis of the collected images, meetings with staff from the Maintenance Sector (MS), and an online questionnaire were carried out to understand the building maintenance failures and management requirements.

2. Background

Drones have proven to be a promising technology for periodic inspections in buildings, allowing for the collection of images from hard-to-reach locations, high altitudes, and high resolution. This approach enables closer examination of facades and roofs, facilitating the capture of anomalies that are not observable from a distance (Ballesteros and Lordsleem Junior, 2020). Additionally, BIM provides a common platform for digitally creating and managing all construction project resources from conception to operation (Ragab and Marzouk, 2021). This technology allows for visualization of the final product in a simulated environment, helping to identify potential problems and risks (Zomer et al., 2021), thus providing significant benefits to all stakeholders in the construction sector. In this regard, the ability to integrate visual assets into BIM can enhance the potential of using these technologies for maintenance management, as the models become even more effective when updated, generating information that holds excellent value (Solla et al., 2020); (Rodrigues et al., 2023). (Table 1) presents the state of the art of drone and BIM integration to support building Maintenance Management (GM).

(Solla et al., 2020) adopted a classifier algorithm called 'k-nearest neighbors,' applied to the set of visual assets collected by drones, aiming to detect patinas and black crusts present on the stone facade of a historic building. Other issues, such as alveolization and infiltrations, still need to be addressed due to the algorithm's limitations. The integration of information regarding the detected damages with the BIM model was carried out by modeling the coating layers according to the surfaces of the analyzed elements. The proposed method has inherent limitations related to the image analysis algorithm, making it insufficient to identify pathological manifestations that do not exhibit a significant visual contrast when compared to their surroundings.

(Tan et al., 2022) presented a study that focused on automatically identifying cracks in facades. They used a deep learning algorithm called Mask R-CNN to analyze images collected by drones, which segments defects in the pictures. The cracks were integrated into the BIM model by modeling their outlines as objects in parameterized families. Tan et al.'s work highlighted the technical requirements of this approach, such as the need for sufficiently large databases for the correct operation of the systems, especially for algorithms based on learning. This emphasis on technical requirements is a crucial consideration for researchers and professionals in the field.

(Rodrigues et al., 2023) Developed a manual damage survey method using a 3D model produced on the ArcGIS Pro platform, created from drone images. In the model, the damages are indicated by creating polylines, with layers corresponding to the problems detected. The authors above created a database for storing information for the visual model, suggesting the possibility of integration with BIM to support analyses and future inspections. However, the method of representing damages presented in the work needs to provide guidelines to standardize the identification process. Another area for improvement regarding the work relates to the superficial treatment of the integration of assets into BIM, presenting this process in the results.

(Matos et al., 2023) presented a manual procedure for damage detection. After collecting images with drones and cameras, a BIM model was created in which pathological manifestations were represented by creating families containing placeholders. These elements carry information about the problems and their severity, represented by the element's color inserted in the BIM model. The use of placeholders allowed for the identification of the damage positions; however, the visual representation of the method could be more precise and has limitations, potentially confusing in cases with many pathological manifestations concentrated in one area.

ISSN: 0718-5073

Vol. 39
Nº3 2024
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Table 1. State-of-the-art regarding the integration of drones and BIM to support Building Maintenance Management.

Source	Object	Anomalies	Digital Technologies applied to		Do the authors discuss how the technique can be integrated into MM?
			Data acquisition	Data processing	
Tan *et al.*, 2024	Façades	Cracks	UAS (automatic flight)	Revit (Autodesk); Edge Computing, Star Algorithm; Genetic Algorithm (GA); K-Means Algorithm	No
Gan *et al.*, 2023	Bridges	Cracks	UAS (manual flight)	Revit (Autodesk); Faster R-CNN Algorithm	No
Rodrigues *et al.*, 2023	Cultural Heritage	Stains; coating disintegration; cracks	UAS (automatic flight); Terrestrial Laser Scanning (TLS); Real Time Kinematic (RTK); DroneDeploy (DroneDeploy)	Revit (Autodesk); SketchUp Pro (Trimble); ArcGis Pro (Esri)	Yes
Matos *et al.*, 2023	Façades	Cracks; stains	UAS (manual flight); Digital Single-Lens Reflex (DSLR) camera	Revit (Autodesk); Metashape (Agisoft); Autodesk ReCap; Dynamo (Autodesk)	Yes
Tan et al., 2022.	Façades	Cracks	UAS (automatic flight); Real Time Kinematic (RTK)	Revit (Autodesk); Mask R-CNN Algorithm; Dynamo (Autodesk)	Yes
Jofré-Briceño *et al.*, 2021	Port infrastructure	Cracks; corrosion; coating detachment	UAS (manual flight)	Revit (Autodesk); Excel (Microsoft)	Yes
Xu; Turkan 2020	Bridges	Cracks	UAS (manual flight)	Revit (Autodesk); MATLAB; BIM 360 Glue; Notepad ++	Yes
Solla *et al.*, 2020	Cultural Heritage	Patina; biogenic crusts	UAS (manual flight); Terrestrial Laser Scanning; Ground Penetrating Radar (GPR); Infrared Thermography	Revit (Autodesk); ReCAP (Autodesk); eCognition Developer v9.5 (Trimble); K-Nearest Neighbor (KNN) Algorithm	No
Ribeiro *et al.*, 2020	Façades	Biological colonies; efflorescences; cracks; exposed rebars	UAS (Automatic Flight); Real Time Kinematic (RTK); Pix4D	Revit (Autodesk); Image Processing Toolbox (MATLAB); Dynamo (Autodesk); Navisworks (Autodesk)	No
Serrat *et al.*, 2020	Façades	Capillary moisture; chipping; soiling;	UAS (manual flight); Pix4Dmapper (Pix4D)	Revit (Autodesk); QGIS	No

The reviewed studies provide an overview of research integrating visual data obtained by drones into BIM models to support building maintenance. Automatic detection processes entail certain limitations, particularly related to the technical requirements of the images and the need for large databases for learning-based algorithms (Tan et al., 2022). Furthermore, the representations of damages, even in more visual studies like those by (Rodrigues et al., 2023) and (Matos et al., 2023), still need more detail. Most works utilize advanced tools for collecting visual data, which can make the methods costly.

Although all studies use drones as the primary technology, some incorporate additional tools to support the methods. (Rodrigues et al., 2023) And (Solla et al., 2020) employed terrestrial laser scanners, while (Tan et al. 2022) and (Ribeiro et al., 2020) used Real Time Kinematic (RTK) technology for georeferencing. However, these tools require significant investments. Thus, there is a need for methods that offer guidelines for image collection with drones and their integration into BIM, especially in the context of low adoption of digital technologies and limited financial resources, which is the focus of this work.

The Systematic Literature Review (SLR) revealed that, despite studies on the collection of visual assets from buildings and other construction products, there needs to be a significant gap in integrating these methods into the maintenance management processes of the analyzed structures. Studies such as those by (Rodrigues et al., 2023), (Matos et al., 2023), (Tan et al., 2022), (Xu and Turkan, 2020), and (Ribeiro et al., 2020) superficially discuss the possibilities and recommendations for this integration. In contrast, (Jofré-Briceño et al., 2021) developed a detailed workflow to maintain port infrastructure. Still, their approach has limitations, as the representation of the anomalies in the BIM model is done solely by altering the colors of the modeled elements, which becomes inadequate when these pathologies have varying characteristics along a component or system.

Therefore, studies on integrating drones and BIM models for building inspection with a focus on building maintenance still need to be made available. Most studies concentrate on the automatic detection of damage using advanced technologies, such as laser scanners (Tan et al., 2024); (Gan et al., 2023); (Tan et al., 2022); (Xu and Turkan, 2020); (Solla et al., 2020); (Ribeiro et al., 2020); (Serrat et al., 2020). Only (Jofré-Briceño et al., 2021), (Rodrigues et al., 2023), and (Matos et al., 2023) address manual processes for integrating visual data into BIM without utilizing image processing algorithms. Other analyzed authors do not discuss intervention aspects or data integration into maintenance routines. Suggestions for

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Vol. 39
Nº3 2024
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improving the connection between research and management practices include more detailed recommendations on protocols and responsibilities for implementing the proposed methods.

3. Research Method

The research strategy adopted in this study is the Case Study approach, an empirical method to investigate a phenomenon within its real-life context (Yin, 2009). The practical problem identified in this research relates to the challenges in generating information about the current condition of buildings, which hinders the maintenance management of facades and roofs, particularly in public educational buildings. As a solution, a method was proposed for integrating drone imagery and BIM in the facades and roofs of educational buildings as a tool to support maintenance management.

A public higher educational institution was selected for this study, with a department responsible for maintaining its buildings and infrastructure (MS). The institution manages around 187 buildings in the State of Bahia-Brazil, most of which are in Salvador City. These buildings range from 19th-century construction to more recent 21st-century structures. The MS has approximately 189 direct and indirect staff members who design, plan, budget, construct, maintain, and inspect buildings.

3.1 Systematic Literature Review (SLR)

A systematic literature review (SLR) was conducted to identify the theoretical problem. This approach is characterized by a review of a clearly and objectively formulated question that uses systematic methods to select, identify, and analyze research on a given topic (Kitchenham, 2004); (Moher et al., 2009); (Dresch et al., 2015). This process aimed to provide an initial overview of studies related to the context to which this work seeks to contribute. A set of search terms (Figure 1) was created and used to search in the Scopus and Web of Science databases. Subsequently, the sample was refined using inclusion and exclusion criteria to obtain a more representative and valuable final sample for identifying methods for analyzing and integrating visual assets collected by drones into BIM in studies related to maintenance activities. This research approach was chosen for its ability to provide a targeted sampling of the state of the art related to the scope of this study throughout a systematic search of databases.

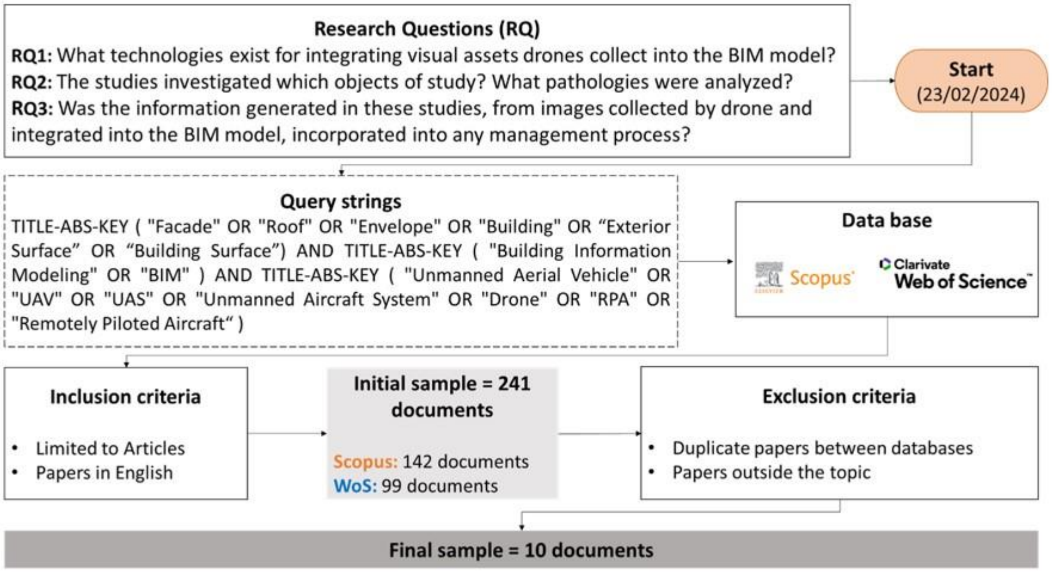

Figure 1. SLR.

The initial sample of articles from the Scopus and Web of Science databases included 241 studies. Step 1 involved removing duplicate articles by comparing their titles, resulting in a sample of 168 articles. In Step 2, a filtering process was conducted by reading the titles of the studies, excluding those that exclusively used data collection tools not relevant to this study's proposal (e.g., "Terrestrial Laser Scanner"); studies with significantly different subjects compared to buildings (e.g., "Agricultural"); stages other than the use phase (e.g., "Construction Progress Monitoring"); environments that are not external to buildings (e.g., "Indoor Path Planning"); articles that did not indicate a relation to damage detection in envelopes or methods for integrating visual assets into BIM (e.g., "Earthwork Volume Calculation"); and review papers that were not excluded by the filter incorporated into the search string. As a result of Step 2, 42 articles remained. Step 3 involved reading the abstracts and

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Vol. 39
Nº3 2024
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applying the same criteria as in Step 2, leaving 29 studies for the next stage. In Step 4, full-text readings of the articles were performed, applying criteria similar to those used in Steps 2 and 3. Finally, the current sample related to the search string includes ten articles. The results obtained in this stage are presented in Section 2 of this paper.

3.2 Case Study

This case study aimed to gather data about the current condition of the buildings using drones and the designs of the investigated buildings to conduct a preliminary mapping of the institution's maintenance management system. This research approach was chosen because this study is part of a larger project linked to a master's thesis and a doctoral dissertation, and it meets the methodological prescriptions necessary for understanding the maintenance management system of the selected Educational Institution.

The initial step was inspecting the condition of ten buildings' roofs, coverings, and facades at the studied educational institution and identifying challenges associated with drone data collection. The buildings were selected in collaboration with the institution's maintenance sector (Figure 2) to create a sample representing the other buildings managed by the department. Factors such as system typologies and the general state of conservation of the buildings were considered in the selection process. Data was collected using a drone DJI Air 2S, with an integrated camera, sensor 1” CMOS, 20 MP as Effective pixels, Image size of 4572x3648/5472x3079, and Photo Format JPEC/DNG (RAW). (Table 2) details the selected buildings, and (Table 3) offers insights into the drone data collection process.

Figure 2. Representative images of inspected buildings.

ISSN: 0718-5073

Vol. 39
Nº3 2024
DOI: 10.7764/RIC.00115.21

Table 2. Information on the buildings selected in the case study.

Building	Roofing systems	Facade finishes	Approximate age
E01	Ceramic roof	Painting; Stonework; Ceramics	360 years
E02	Ceramic roof; Polycarbonate roof	Painting; Stonework	215 years
E03	Fiber cement roof; Reinforced concrete slabs	Painting	70 years
E04	Metal tiles; Reinforced concrete slabs	Painting	>10 years
E05	Fiber cement roof; Reinforced concrete slabs	Ceramic; Has unfinished areas	10 years
E06	Fiber cement roof; Reinforced concrete slabs	Painting; Ceramics	10 years
E07	Fiber cement roof; Reinforced concrete slabs	Painting; Exposed concrete	55 years
E08	Ceramic roof	Painting	>200 years
E09	Ceramic roof; Fiber cement roof; Reinforced concrete slabs	Painting; Ceramics	40 years
E10	Fiber cement roof; Reinforced concrete slabs	Painting; Ceramics; Has unfinished areas	15 years

Buildings	Inspection date	Drone used	Distance traveled (m)	Maximum altitude (m)	Flight duration (min)	Number of images	Projects	
							CAD	Revit
E01	15/01/24		1018	48	61	809	●	
E02	19/01/24		2691	99	96	991	●	
E03	22/01/24		1632	78	46	324	●	
E04	22/01/24		810	55	21	259	●	
E05	24/01/24	DJI Air 2S	938	75	25	209	●	
E06	24/01/24		1517	65	42	400	●	
E07	24/01/24		3496	117	63	574	●	
E08	24/01/24		678	43	23	185	●	
E09	26/02/24		951	50	37	300	●	
E10	08/07/24		2821	100	46	796	●	●
Total	-	-	**16.552**	**117**	**460**	**4.847**	-	-

After acquiring the images of the buildings, those were analyzed to identify the prominent anomalies in the building envelopes. The results of this analysis were presented in a meeting with about 20 professionals from the institution's maintenance department to gather initial feedback on the collected data and understand the actual maintenance management needs.

The next step involved creating a Google Forms questionnaire to identify the challenges the maintenance management team perceived and define priorities for developing the solution. The questionnaire was structured into two main categories: the first aimed at determining the respondents and their roles within the maintenance sector, and the second focused on gathering insights about the current state of the maintenance sector and the managed buildings (Figure 3). A pre-test was conducted with two individuals to evaluate the clarity and functionality of the questionnaire before sending it out to the staff. Information about the participants is detailed in (Table 3).

ISSN: 0718-5073

Vol. 39
Nº3 2024
DOI: 10.7764/RIC.00115.21

The data were grouped into four categories for the interview analysis, summarizing the main problems identified through the responses: (1) Management and Process Planning, (2) Human Resources / Training, (3) Financial and Technological Resources, and (4) Operation and Infrastructure.

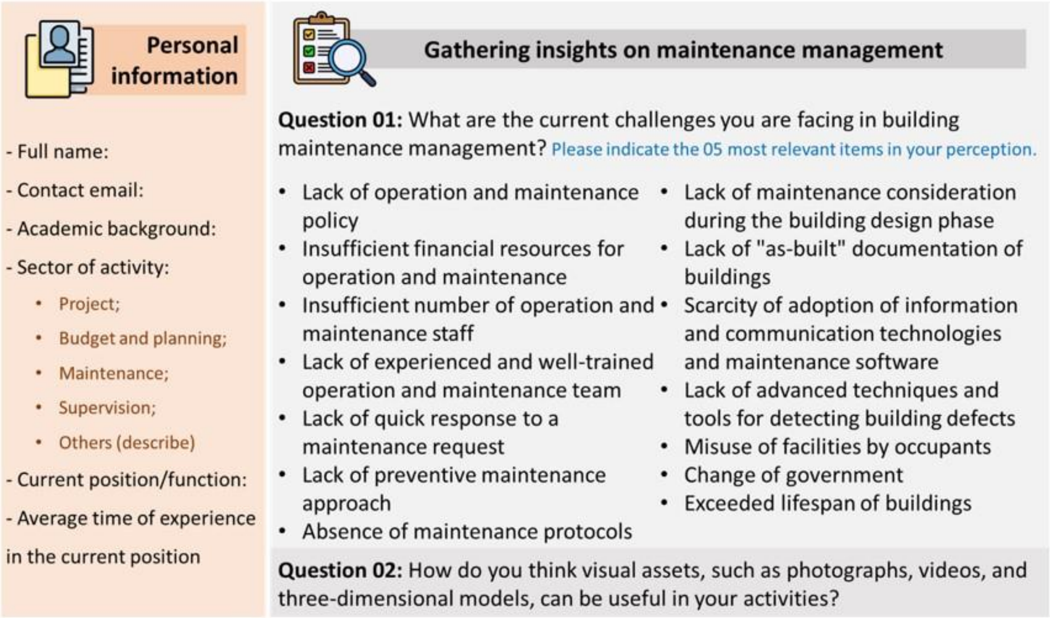

Figure 3. Applied questionnaire.

Table 3. Respondent profile.

Academic background	Area of Work	Position or function held	Average length of experience in current position
Architecture and Urbanism	Project	Architect and Urban Planner	11 years
Electrical Engineering		Electrical Engineer	5 years
Civil Engineering	Planning and Budgeting	Head of Budget and Planning	43 years
		Budget and Planning Analyst	8 years
Civil Engineering	Maintenance	Technical Operational Analyst III	7 years
		Civil Engineer	7 years
Logistics		Maintenance inspector	4 years
Civil Engineering	Oversight	Administrative Operational Assistant III	7 years
		Support for construction inspection	7 years
		Operational Assistant III	7 years
		Administrative Assistant III	8 years
		Operational Inspection Assistant	7 years

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Vol. 39
Nº3 2024
DOI: 10.7764/RIC.00115.21

4. Findings

This section presents the case study results and the proposed method for integrating drone images with BIM for facades and roofs of educational buildings as a maintenance management tool. A total of ten buildings were inspected. From the 4,847 images collected, it was possible to analyze the current conditions of the facades and roofs. (Table 4) highlights the prominent anomalies identified in the envelopes of the inspected buildings.

Table 4. Survey of the main anomalies in the envelope.

Occurrence	E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	Frequency
Cracks in coatings	●	●	●	●	●	●	●	●	●	●	100%
Peeling of coatings	●	●	●	●	●	●	●	●	●	●	100%
Stains or accumulation of dirt	●	●	●	●	●	●	●	●	●	●	100%
Vegetation growth	●	●	●	●	●		●	●	●	●	90%
Damaged tiles	●	●	●	●		●	●	●	●	●	90%
Damaged windows	●	●		●	●	●	●	●	●	●	90%
Inadequate plumbing installations	●	●	●	●	●		●	●	●	●	90%
Inadequate HVAC installations			●	●	●	●	●	●	●	●	80%
Concrete rebar exposure							●			●	70%
Detachment of coating				●	●	●	●	●	●	●	70%
Inadequate electrical installations	●		●	●			●	●	●	●	70%
Cracks in subfloor				●	●	●	●				40%
Missing tiles	●					●			●	●	40%
Absence of coatings (interrupted construction)						●				●	20%

The analysis of the collected images revealed fourteen types of occurrences in the systems that make up the building envelopes. The most commonly identified issues were cracks in facades and roofs, paint peeling, and dirt accumulation observed in all inspected buildings. Significant incidences of vegetation growth on roofs and facades were noted, along with improper placement of electrical, plumbing, and HVAC installations and various window frame damage.

(Table 4) illustrates problems arising from two primary sources: failures or lack of maintenance and misuse of the buildings. Issues related to significant wear on system components and the accumulation of dirt on finishes or roofs support the hypothesis of inadequate preventive maintenance. The arrangement of electrical and plumbing components contrary to technical standards indicates a lack of guidelines for interventions in the envelope systems, whether for maintenance or the installation of new equipment. The observed scenarios underscore the crucial need for adopting new technologies for information management, enabling more accessible access to updated building data and facilitating efficient decision-making, thereby revolutionizing building management practices.

(Table 5) presents the responses from the questionnaire administered to the maintenance management team. The results were grouped into four categories, summarizing the main problems identified through the responses.

ISSN: 0718-5073

Vol. 39
Nº3 2024
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Table 5. Respondents' Perception of Difficulties in Maintenance Management Performance.

Options	Answers	Respondents (%)	Categories
Lack of a preventive maintenance approach	9	75%	Management and Process Planning
Lack of "as-built" documentation of buildings	8	67%	
Lack of consideration for maintenance in the building design phase	7	58%	
Absence of maintenance protocols	3	33%	
Lack of operation and maintenance policies	2	17%	
Insufficient operation and maintenance staff	6	50%	Human Resources / Training
Lack of an experienced and well-trained operation and maintenance team	2	17%	
Insufficient financial resources for operation and maintenance	7	58%	Financial and Technological Resources
Lack of adoption of information and communication technologies and maintenance software	4	33%	
Lack of advanced techniques and tools for detecting building defects	2	17%	
Lack of "as-built" documentation of buildings	8	67%	Operation and Infrastructure
Lack of prompt response to a maintenance request	5	42%	
Misuse of facilities by occupants	2	17%	
Decay of the buildings' lifespan	2	17%	
Change of government	0	0%	

The responses obtained from the questionnaire and the records from the initial meeting revealed that the most significant impact is related to the institutional culture, highlighting the absence of preventive maintenance as the most recurring issue. This problem is connected to the need for more workforce, financial resources, and updated building documentation, which prevents managers from adopting a preventive approach. The lack of consideration for maintenance during the design phase of the buildings also reinforces the hypothesis of a cultural issue. This study aims to address these needs by promoting greater efficiency in maintenance management through the collection and management of updated building information, thereby validating the use of the proposed technologies.

The analysis of the open-ended responses from the managers highlighted five key points regarding the visual assets: (1) facilitating the assessment of building conditions; (2) aiding decision-making; (3) supporting the development of processes and projects; (4) simplifying the supervision of executed services; and (5) updating building information. These responses confirm the need for actions that enhance process efficiency in the context of low digital maturity and institutional constraints. The case study confirmed the suitability of the methods identified in the Systematic Literature Review (SLR) for the actual conditions of the education institution studied, highlighting the lack of applicable methods in low-digitalization contexts and the need for low-complexity digital tools as a promising alternative.

Based on the collected and analyzed data, a preliminary diagnosis of the participating maintenance management (MM) system was obtained, revealing four main limitations: 1) lack of information on the current condition of the building envelope; 2) lack of standardized and transparent processes; 3) difficulty in communication among stakeholders; and 4) absence of a preventive maintenance approach.

(Figure 4) presents a preliminary proposal for integrating drone images and BIM in educational public buildings to support maintenance management. This proposal is composed of five stages, developed based on the case study results and in light of the systematic literature review. The proposed method integrates data acquisition processes through drone inspections and the processing of collected data via photogrammetry, represented in a BIM model. This integration would enable the maintenance management (MM) team to generate updated data and conduct a qualitative and quantitative analysis of the building envelope. Finally, implementing the outputs from these activities, such as images, reports, damage maps, and meetings, would make the MM process more transparent and standardized.

ISSN: 0718-5073

Vol. 39
Nº3 2024
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In addition to implementing a pre-established workflow, a feedback loop was proposed to evaluate the method's effectiveness. This evaluation aims to verify whether the information generated supports decision-making regarding maintenance management (MM). If new limitations arise, they will be incorporated into the proposed method. Thus, the proposed method broadly includes guidelines for developing each stage, making the method replicable and easy to use.

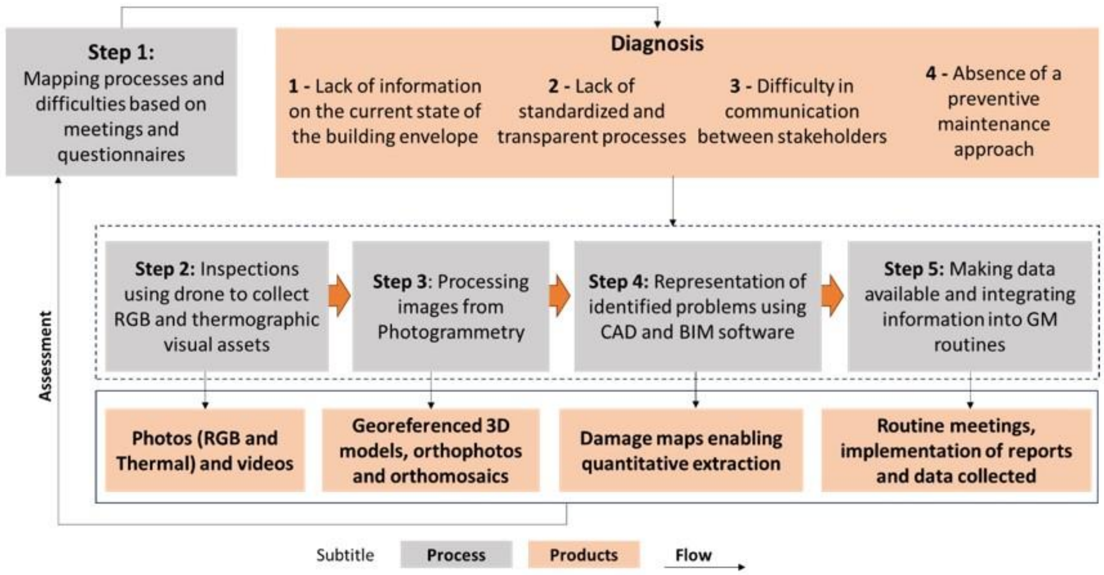

Figure 4. Design of the proposed method for integrating drone images and BIM in educational public buildings to support maintenance management.

5. Discussion

The results presented in this study reflect a scenario of deficient building maintenance management, as previously reported by (Büron, 2018), who discussed the need for training and awareness among public institution managers, recommending a proactive approach to building care. The inspected buildings exhibit various distinct typologies in their façade and roof systems. Some buildings operate continuously and are dedicated to teaching, research, and administrative activities. The diversity of configurations in university buildings, as discussed by (Rizzatti, 2002), (Ferreira, 2017), and (Moreno, 2022), makes them complex and requires intense dedication from managers to ensure they function in a fully operational and safe manner.

Regarding the proposal for integrating drone images and BIM for façades and roofs of buildings as a tool to support maintenance management, this method advocates the use of accessible technologies, in contrast to the studies mapped in the literature, such as those by (Ribeiro et al., 2020), (Solla et al., 2020), (Tan et al., 2022), and (Rodrigues et al., 2023). In addition to utilizing high-cost technologies, these studies did not include guidelines for implementing their methods.

Moreover, the proposed method was designed to facilitate implementation by presenting a flow between processes, stages, and products, a feature not observed in the method by (Rodrigues et al., 2023). Regarding products, the objective of the meetings for presenting the identified situations represented through damage maps is to involve the entire maintenance management (MM) team, aiming to assess the clarity of the representation of anomalies. The significance of this damage map was noted during the analysis of the method proposed by (Matos et al., 2023), whose visual representation could be more transparent and present limitations. Additionally, routine meetings to present inspection results reinforce the adoption of preventive maintenance practices, as the results can be useful for corrective maintenance and for identifying potential future issues, thereby promoting preventive practices.

ISSN: 0718-5073

Vol. 39
Nº3 2024
DOI: 10.7764/RIC.00115.21

6. Conclusions

This study presented the preliminary proposition of integrating drone images and BIM for the façades and roofs of educational buildings to support maintenance management, aiming to facilitate access to information about the integrity of building envelopes in public buildings with low digital maturity. To support the proposal, a Systematic Literature Review (SLR) was conducted to identify gaps and directions, guiding the structuring of the method. Additionally, a case study was conducted at a public educational institution involving inspections of ten buildings to analyze the prominent anomalies in the building envelopes and map the main difficulties in maintenance management, providing insights into the method's development.

The literature review revealed a need for solutions applied in contexts with low digital maturity, given the widespread adoption of high-cost and complex capture tools in the analyzed studies. The case study at the selected institution yielded findings consistent with those of the systematic literature review, indicating maintenance management issues related to the absence of a preventive culture and a labor shortage within a context of low digitalization of both tools and processes. Adopting low-complexity methods, using easily accessible and trainable equipment, was seen as a promising alternative. The main problems identified during the case study inspections included the absence or failure of maintenance and the need for clear intervention guidelines. During image analysis, the potential of drones for data acquisition was observed, demonstrating high efficiency in this activity.

Regarding the study's limitations, it is acknowledged that significant research may have been excluded from the sample during the state-of-the-art SRL investigation. The investigation of a specific Educational Institution does not bring the general context of the country, despite similar studies pointing to the same scenario. Thus, the case study is restricted to the regional context of an Educational Institution located in the country's northeast region. In addition, the questionnaire respondents represented a small percentage of the participating maintenance management (MM) sector, making it challenging to convey the limitations encountered with accuracy and generalization. Finally, physical limitations regarding the surrounding conditions, such as tree canopies and other obstacles, made it difficult to collect drone imagery.

Future studies will involve implementing the proposed method in two case studies and evaluating and refining it. The aim is to support the maintenance management (MM) sector, improve transparency of information and processes, and result in more efficient and routine maintenance management.

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