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Technological roadmap integrating TPM and BIM in the management of building maintenance of federal universities

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Abstract: Planning of maintenance activities is the basis for the effective operation of service and restoration of public buildings. Currently, there are technological tools that can help to improve building management and maintenance, such as BIM (Building Information Modeling) and TPM (Total Productive Maintenance) the integration of these two concepts can bring significant gains to building maintenance. This work developed a technological roadmap integrating BIM and TPM, such as a tool to improve building maintenance management, focusing on reducing maintenance costs and prioritising preventive maintenance. This research has been developed through a systematic literature review, followed by the elaboration and application of the Roadmap, which evaluates after application in a pilot project at a federal university. The results have shown that the incorporation of the Roadmap into the routine of the maintenance sector provided higher control by the management, reducing corrective problems and extending the useful life of machines and equipment. The acceptance of the team involved in the process was positive, demonstrating the proposed project's potential. This study concludes that using the technological Roadmap, integrating BIM and TPM, proved promising and coherent with the expectations for building maintenance management. In addition, it offers a guide to help the application and use of the Roadmap in other institutions, with future perspectives to expand the impact of this approach on building maintenance management in different environments. Therefore, this research represents a relevant contribution to federal Universities, providing a technological tool to optimise building maintenance management.

Keywords: Roadmap; Technological Innovation; Total Productive Maintenance; Building maintenance management; Building Information Modeling.

1. Introduction

With technological advancement, methodologies and management systems have been developed to assist in managing engineering projects and building maintenance, maximising the effectiveness of construction systems (Brockmann *et al.*, 2016). Based on this premise, public construction managers face the challenge of identifying new solutions and improvements in materials, processes, equipment and management techniques to reduce the risk of inertia, deterioration and obsolescence, seeking increased development and productivity (Cooke, 2000; Sacks *et al.*, 2010).

Building maintenance activities should cover the original condition to the eventual deterioration of equipment and facilities, involving introducing improvements to avoid failures (Aguiar, 2023). Planning maintenance activities is the basis for effectively operationalising the attendance services and recovery of public buildings. Some tools can help improve building management and maintenance, such as BIM (Building Information Modeling) and TPM (Total Productive Maintenance). However, with the requirements at the level of productivity comes the need to integrate techniques and processes (Duodu; Rowlinson, 2021)

In a university, planning maintenance activities is the basis for effectively operationalizing attendance services and recovering buildings and equipment used by students, teachers, and public servants (Duodu; Rowlinson, 2021). According to Lima (2006), maintenance activity in public buildings contributes to maintaining the correct performance of the buildings, in addition to ensuring safety, sustainability, appreciation and quality of them, meeting the needs and requirements of its users.

In the search for instruments that facilitate maintenance management, Total Productive Maintenance (TPM) methodology can be used to manage preventive maintenance and equipment improvement (Aguiar, 2023). However, some problems and challenges are faced by universities, such as the ageing of the buildings built, lack of preventive monitoring, technical knowledge of managers, and investments, among others, generating a reduction in the useful life of buildings (Degasperi et al., 2017; Gavazza; Neto, 2015).

Thus, thinking of tools that help maintenance management, we have BIM, a technology in the area of engineering and architecture that associates several components of a project, such as hydraulics, electrical and architecture, with the aid of virtual modelling, to identify incompatibilities and potential information, facilitating the execution from the design phase of the project, until its demolition, also including the maintenance phase (Degasperi *et al*., 2017).

Given this, the interconnection of methodologies and techniques that help the development of the different sectors within civil construction is necessary (Sacks *et al*., 2010; Aguiar, 2023). In order to obtain a tool that assists in the management within a public university, this work elaborated a technological roadmap. This method allows the creation of prospective visions and elaborating actions listed in a short, medium, and long-term time horizon.

It is innovative research which sought to align BIM technology, which should be used in the direct or indirect execution of engineering works and services, with the TPM methodology that has in its foundations the search to increase the total availability of the installation, the quality of the product and the use of resources, in a roadmap with clear guidelines for implementation and use.

2. Theoretical Review

2.1 Building Maintenance Management

A building presents a contiguous number of phases and activities that it goes through over time, from its planning and design to its eventual demolition, rehabilitation, or reuse (ABNT, 2009). The expression 'maintenance' began to be noticed in the vocabulary from 1930 through the military groups that should keep all the material at an acceptable level of functioning and conservation (Carreira *et al*., 2010). The set of technical and administrative actions that proposes to maintain or re-put into operation equipment, installation, or machinery of a specific sector through correct and timely interventions is called maintenance (ABNT, 1994).

Maintenance management arose from planning and evaluating procedures and integrating with other organisation sectors to reduce costs, especially by avoiding corrective maintenance, reducing waste and managing inventory (Morilha, 2023).

For adequate functioning of maintenance, there must be planning that makes it possible to identify and register the existing systems and equipment, create monitoring plans (through service orders, for example), monitor and sizing of teams and work control and obtain management reports of the services (Morilha, 2023).

2.2 Total Productive Maintenance (TPM)

According to Kardec and Nascif (2013), Total Productive Maintenance (TPM) emerged after the Second World War, in the automobile factories in Japan, as an evolution of the already known preventive maintenance and underwent several changes in its procedures until the current form.

Like a standard/residential house, the TPM starts with a base (foundation) based on the 5S, on which the pillars rest to keep the roof firm and robust. In the TPM house, the pillars represent the various competencies that must develop, and the roof corresponds to the TPM model itself (Figure 1) (Rocha, 2011).

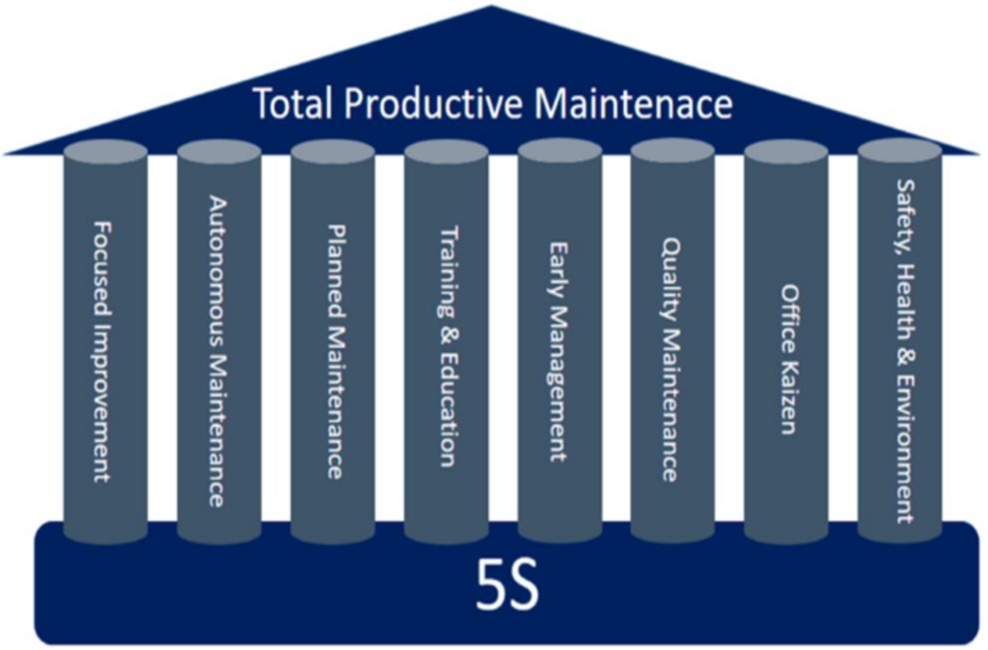

Figure 1 - The TPM house. Image provided By Erik T. Hansen. Kardec and Nascif (2013)

According to Matos (2008), the 5's are *Seiri (organisation), Seiton* (*tidiness*), Seiso *(cleaning),* Seiketsu (*personal cleaning or standardisation) and* Shitsuke (discipline). Note that the 5S tool, which helps in the lean construction process, also has a preponderant role in the TPM methodology, as it is the basis that supports the entire methodology. The application of 5S aims to reduce the waste generated by disorganisation in the work environment and make the work environment safer, reducing waste of time and materials (Guedes, 2009).

The eight pillars supporting the entire TPM methodology are developed with the foundation understood and well-defined. These pillars are:

- Autonomous maintenance: Low-complexity maintenance starts in the equipment and extends to all production. Carried out by the equipment operators, it aims to ensure a high level of productivity, in addition to mobilising the operator of his responsibility for his equipment (Almeida; Fabro, 2019).

- Planned maintenance: is the pillar responsible for maintenance planning. It should be managed by the company's maintenance sector, by people with technical training and knowledge of equipment so that it is possible to increase the efficiency of the equipment and its availability for use (Menezes *et al.*, 2015).

- Specific improvements: seeks to understand where the most considerable losses of each sector or equipment are so that it is possible to implement improvements to reduce them (Souza, 2001).

- Education and training: a foundation that raises awareness and enables people to achieve maximum productivity. It requires that those involved in the maintenance process receive training and education, as well as assist in the search for self-development (Ribeiro, 2016);

- Quality maintenance: It is related to the efficient repair of machines ("zero defect" of products) and corresponds to the sector that performs the quality control must act in conjunction with the sector that does the maintenance management (Biehl, Sellitto, 2015).

- Initial control: So that there are no problems with equipment due to a lack of information related to the history of operation, this pillar indicates that it is essential to carry out a unified management of maintenance of new equipment (Menezes *et al.*, 2015);

- Administrative TPM: aims to improve the flow of processes in all company areas related to maintenance, avoiding unnecessary bureaucracy, with an increase in the quality of information and the speed with which this information will transmit (Souza, 2001);

- TPM - hygiene, safety, and environment: This last pillar aims to maximise productivity with zero accidents and zero pollution. Maintenance activities must include operational safety, work, and occupational health, and reducing environmental impacts (Ribeiro, 2016).

According to Nakajima *et al*. (1994), the implementation of the TPM goes through four phases: Preparation, Introduction, Implementation and Consolidation. These steps can be subdivided into twelve steps, as shown in Table 1:

Table 1 - Steps in applying the TPM.

Phase	Stage	Premise
Preparation	1. TPM start announcement	Depends on leadership participation
	2. Awareness and training	Through courses and lectures for all
	3. Structuring for implementation	Secretarial training with groups and committees
	4. Internal policies and guidelines	Establishment of objectives and goals
	5. Elaboration of the master plan	Meeting of events to conduct the TPM
Introduction	6. TPM starting point	Formal presentation of the beginning of TPM
Implantation	7. Implementation of productive pillars	These pillars are: Improvement Specific, Autonomous Maintenance, Planned Maintenance and Education and Training
	7.1 Specific Improvement	Cross-functional teams to eliminate big losses
	7.2 Autonomous Maintenance	Operator "adopts" the machine he works with and takes care of its conservation
	7.3 Planned Maintenance	Search for "zero breakdown/failure" and maintenance planning
	7.4 Education and Training	Re-education and individual training of workers
	8. Initial Control Pillar	At the beginning of the project, look for equipment, processes and products that are easy to install
	9. Quality Maintenance Pillar	Search for excellence in quality, through the "zero defect" of products
	10. Administrative TPM	Quality of information passed between departments
	11. Safety, Hygiene and Environment Pillar	Care for the environment (zero pollution) and zeal for safety (zero accidents)
Consolidation	12. Consolidation and improvement	Correction of found failures and definition of new goals

Adapted from Nakajima (1994)

The case study of Cavalcante Filho (2016) reports the benefits of implementing TPM in the industry under study, with the reduction of anomalies in the organisation, increased quality of life of employees and improved communication between the production and maintenance sectors. Results achieved by César *et al*. (2014), who applied the TPM in a multinational company in the food segment, managed to reduce the downtime of the equipment, and with this, increase the efficiency of the same was around 71.4% and after the TPM reached 90.4%.

A study on TPM and building maintenance in hospital buildings carried out by Monte (2017), where there was the application in building maintenance of operational procedures (SOP) associated with the concepts of the TPM, and it was concluded that the guidelines were understood, accepted and applied correctly, generating satisfactory results. However, it highlighted the need for training by the employees responsible for the activities.

The study conducted by Cavalcante Filho (2016) shows the implementation of the "Initial Control" pillar in the protection equipment of the power substation of the State of Maranhão, which allowed the State to leave the last places concerning the number of power outages in Brazil and to position itself among the first. It was due to the possibility of identifying and eliminating problems still at the origin and, implementing improvements in the equipment, making them more robust and reliable (Cavalcante Filho, 2016)

Therefore, implementing TPM can represent essential gains for the environment, including maintenance management, whether in the better organisation of the space and the work routine of employees or even to increase the effectiveness of equipment.

To assist in implementing TPM, a possible tool is Building Information Modeling (BIM). This technology allows associating several projects and construction stages (including the building maintenance stage) with the prior identification of incompatibilities, which helps in productive efficiency.

2.3 Building Information Modeling (BIM)

BIM technology consists of a digital representation of the physical and functional characteristics of a building, which contains all the information of the construction life cycle available in design (Gonçalves, 2014) BIM It is an innovative strategy ensuring high-quality performance, optimising the use of resources, reducing the impacts of construction on the environment, and always helping to ensure resources and availability for future generations (Lian; Liu, 2022),

One of the advantages of BIM technology is the ability to reconstruct or remodel in a simple way, which allows users to perform various simulations on models and obtain, as a consequence, more information for the project or equipment in question (Campestrini, 2015; Martins; Monteiro, 2011). Compared to the traditional method of cost estimation, the method of estimating quantities based on the BIM model can reduce the workload caused by the design change, effectively improve work efficiency, and facilitate the control of the project cost at the initial stage of the project (Marcorin *et al*., 2004).

At the heart of building maintenance, BIM plays a fundamental role in the process by providing complete information on equipment and various components of buildings, which makes it easier to schedule preventive maintenance and equipment improvements so as not to fall into corrective maintenance that, as Marcorin *et al.* (2004) have well defined, It requires that there is a stock of parts to supply the constant breakdowns, which happen unpredictably and, consequently, without the possibility of predicting costs. It is important to remember that BIM provides product modelling and information management that can serve the entire project lifecycle (Dave, 2015).

BIM technology works with design software such as AutoCAD® and AutoDesk® Revit. The ability to exchange data between two or more systems is called interoperability (Martins; Monteiro, 2011). This concept is relevant to the growing demand to retrieve and digitally represent historical structures. It also addresses the limitations of software in automating the direct transformation of projects and the semi-automated approach through virtual modelling reconstruction techniques (López *et al.*, 2018).

In existing buildings, there is a process called retrofit that, according to the NBR 15 575/2013 (ABNT, 2013), It is the "remodelling or updating of the building or systems, through the incorporation of new technologies and concepts, usually aiming at the valuation of the property, change of use, increase of useful life and operational and energy efficiency". Therefore, BIM technology works for projects that were not "born" from this technology and, as Ferreira de Paula (2022), There is a need to adapt old buildings as a way of reuse and economy, in addition to the scarcity of spaces available for new constructions.

In these cases, the Asset Information Model (AIM) has a fundamental role since it can benefit asset managers by reducing risks and costs and increasing productivity, using information models about projects and assets (ISO 19 650-1/ 2022).

The BIM design model segregates information into two categories - geometric and non-geometric, where geometric information is present in the volumetry of the model itself, such as areas, and dimensions, not unlike 3D modellers. The non-geometric information individualises the model's objects regarding the materials used, manufacturers, relationship with other objects, cost, and resistance (Almeida, 2019).

In the civil construction sector, the interest in BIM technology starts mainly in the so-called facilities *management* and information management since there is the possibility of incorporating pertinent project data from the conception, construction phase, operation and maintenance of a building (Ruschel, 2015). Despite the interest of civil construction in BIM technology, operators rarely have the experience to use this technology, and it is still necessary to guide the ease of use, interoperability and maintainability of the technology and pertinent details on maintenance and operation of buildings (Leygonie *et al*., 2022).

For this, the management *of facilities*, after the construction stage, must provide the person responsible for the work with an integrated BIM model that contains the modifications of projects carried out during construction in order to compose a complete database, which the maintenance manager of the building will use to plan the operation and maintenance of the construction systems and equipment, what makes BIM a powerful tool of this management of facilities that covers the work routines in an intelligent and simplified way (Pinheiro, 2016).

In addition, there is also asset management, which refers to the activities performed by maintenance engineering, aimed at applying practices directed to optimising equipment, processes and budgets to leverage their effectiveness (Cardoso, 2017).

On results with the application of BIM, Campestrini *et al*. (2015) found that by gathering the correct information and making it available in the correct format, it is possible to develop continuous improvements in the quality of the civil construction product and that with only the analysis of information and punctual corrections, it is also possible to reduce the causes that lead to building maintenance by about 65%.

Fontes (2014) conducted a study on the integration of BIM associated with maintenance in a hotel service establishment. Initially, the hotel was modelled in 3D using Revit. Subsequently, they developed a maintenance plan. The author made an association between the three-dimensional BIM model and a monitoring service via the mobile web to perform this maintenance and concluded that the BIM connection with the database allowed the maintenance manager to have control of each piece of equipment, especially in the graphic aspect, in addition to improving the management of the building space.

Then, in order to unite the TPM methodology with the BIM methodology in a straightforward strategic direction tool, a *roadmap was elaborated*.

2.4 Roadmap

According to Kostoff and Schaller (2001), a *Roadmap* is an outline depicting a potential path or route within a geographical space, similar to a map. Following a simplified definition, the technological Roadmap is an auxiliary tool in decision-making based on pre-established criteria that provide more satisfactory results (Carvalho; Urbina, 2018; Coelho *et al.*, 2012).

The *technology* roadmap offers a way to identify, assess and select technology variants that address current and future challenges (Coutinho; Bomtempo, 2011).

Figure 2 illustrates the sequential process of delineating a Roadmap in a generalised way.

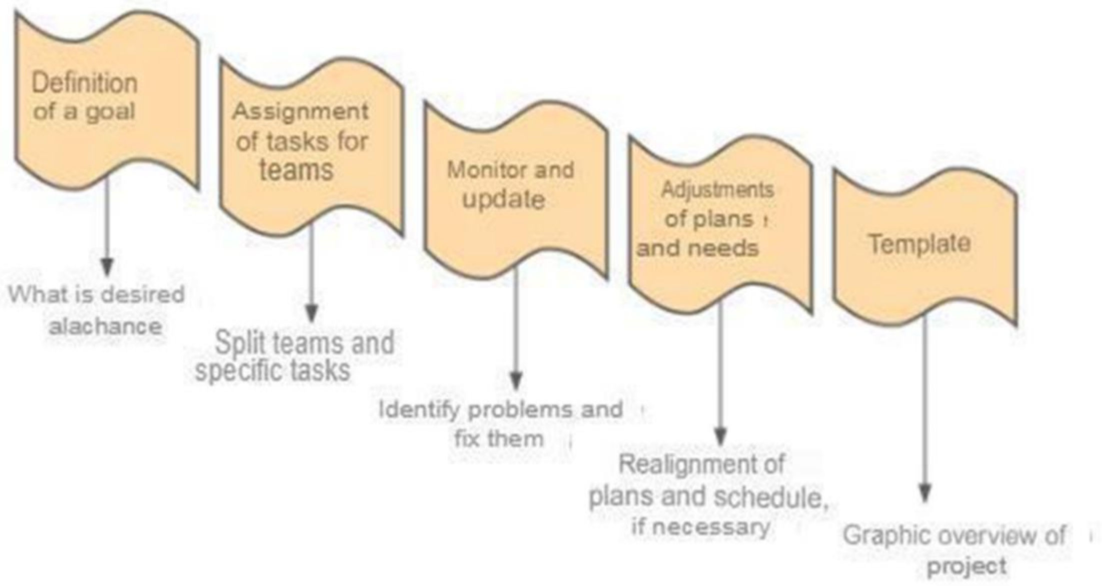

Figure 2 - Flowchart for creating a roadmap.

This flowchart demonstrates that from the definition of an objective, the project manager divides the workforce into work teams and sets specific tasks for each team. Continuous monitoring and reviewing of these tasks make it possible to identify and resolve problems while adjusting plans and aligning them with the new tasks and demands schedule.

Technology *roadmaps* are an interactive process that fits into strategic planning, integrating technology investment decisions with business requirements. Business experts must prepare them and have yet to have a pre-defined standard at the manager's discretion to define the layout (Carvalho; Urbina, 2018).

For the application of a Roadmap, Coelho *et al*. (2012)establish three distinct stages that should follow. The first phase comprises the preliminary activities to satisfy essential conditions for the realisation of the Roadmap (set of needs), being necessary for the internal participation (organisation) and external (interested groups, such as the industrial sector, government, consumers and suppliers). Next, there is the effective development of the Roadmap with identification of the "product", requirements, specifications of the technological areas and what moves this technology (technology drivers), technological alternatives and elaboration of the Roadmap itself, identification and description of each technological area and its current State.

The third phase is the phase of continuity, monitoring and validation of the Roadmap, with analysis of recommended technologies, objectives, development of the implementation plan, and review and update of the study. All stakeholders should be involved in the implementation of the results. Table 2, available in the study by Coelho et al. (2012), summarises developing a *roadmap*.

Table 2 - Process of creating a roadmap.

PHASE I	PHASE II	PHASE III
Preliminary activities	Development	Continuity
• Identify the problem that need the *roadmap* • Define scope and limits • Provide leadership, sponsorship and resources	• Set focus • Identify requirements • Specify technology areas • Identify alternatives and horizons • Prioritize and recommend • Document (*roadmap*)	• Criticize and validate • Develop a plan method of implementation • Review and update when necessary

Adapted from Coelho *et al.* (2012)

3. Methodology

This research holds an exploratory nature of the qualitative character. In order to reach the intended objective encompasses conducting a systematic literature review, formulating a roadmap*, and* ultimately implementing the designed Roadmap (Figure 3).

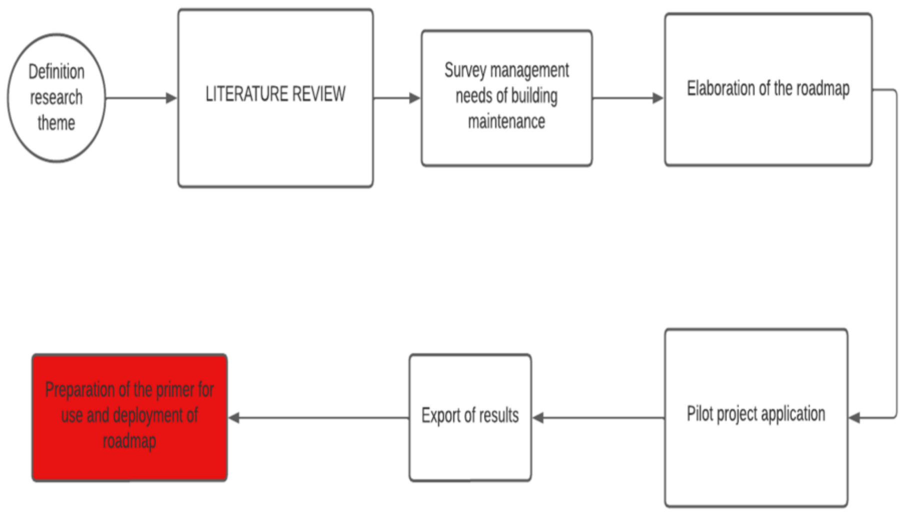

Figure 3 - Research stages

3.1 Systematic Literature Review

Bibliographic survey with a theme pertinent to the subject and analysis sought to answer the following research question: "How can BIM be integrated with TPM to improve building maintenance management processes?" (Material supplementary 1).

In addressing the research question, the study employed specific keywords: building information modelling, Roadmap, technological innovation, total productive maintenance and building maintenance management. The databases used were SciELO, Engineering Science, Science Direct, ASCE Library, Digital Library of Theses and Dissertations (BDTD) and CAPES journals, chosen for their export options in BibTex, CSV and PDF.

To create effective search queries, we formed combinations such as: *"BIM* OR *building information modelling* OR *building information modelling*" AND "*TPM* OR *total productive maintenance* OR *total productive maintenance* AND "*roadmap*" AND *"building maintenance management* OR *maintenance management*" that should appear in the abstract/abstract of the articles.

For selecting articles identified in the research, the following inclusion criteria are date of publication after 2010, presence of keywords in the title and abstract. The establishment of the 2010 cut-off line stems from the surge in publications since the period.

3.2 Elaboration of the technological Roadmap

The preparation of the Roadmap, a survey of the need for improvements in maintenance management, was made based on the information obtained from the literature review. With this information, it is the crucial point for the success of the *Roadmap.*

Phase 1 – Needs assessment: In this stage, one should present information concerning building maintenance, including equipment issues, repair durations, inactivity, budget allocation, and available workforce. At this stage, the manager must present the problems that the sector faces and that he wants to reduce or eliminate.

Phase 2 – Implementation of BIM and TPM: This second phase was developed from the understanding that BIM technology and TPM methodology can (and should) be inserted in the guidelines of building maintenance management, assisting in the objectives of the *Roadmap*, both by Decree 10 306/2020 (Brasil, 2020) and by the examples of success cases presented in this research previously. At this stage, TPM concepts must be understood and applied by all sectors involved while incorporating BIM technology across all phases of the construction process, including design, execution, operation, and maintenance.

Phase 3 – Monitoring and adjustments: Application of the TPM methodology in the routine of maintenance management through Operating Procedures (SOPs), courses and training. Use of software with BIM technology to visually gather information in order to facilitate activities. In this phase, the observation of *using the Roadmap* and assessing the results should be outcomes. Also, at this stage, adjustments should be made to maintain the pursuit of the objectives initially proposed—analysis of the data generated and identification of improvements.

Phase 4 – Consolidation and new objectives: The functionality of the *Roadmap*. At this stage, the manager must confirm the accomplishment of the initially set objectives. If successful, the program consolidates itself, paving the way for establishing new goals.

3.3 Action Research project

After the creation of the Roadmap and following its guidelines, the exploratory phase of this research, called action research, was carried out, which aims to solve the maintenance challenges presented by air conditioners at the university object of study, located in the State of Bahia, by two months, and consisted of the application of phases 1 to 4 of the Roadmap. TPM principles align the study employed Operating Procedures (POPs) and relevant information about devices and their maintenance.

4. Results

With 129 pre-selected articles, the reading and detailed analysis of each one through a file resulted in the final selection of 60 relevant articles that met the inclusion criteria of the research. The analysis by the author allowed us to confront ideas and facilitate the understanding of the selected works.

Among the information collected during the analysis of these articles, the core of each author's work stands out, the main concepts of each work and the incidence of keywords in the *abstracts* (Material supplementary 2). Figure 4 illustrates the incidence of keywords (combined and non-combined) in the 60 articles selected after a systematic literature review. We observed that "Building Maintenance Management" was the most frequent in 30.3% of the articles analysed, highlighting its relevance in building maintenance management. Next, the concept of "Total Productive Maintenance (TPM)" and "Building Information Modeling (BIM)" appear in 21.2% of the studies, evidencing their applicability and importance for the improvement of buildings. The term "Technological Innovation" was found in 19.7% of the studies, indicating its relevance as an improvement strategy for building maintenance management. Finally, "*Roadmap*" was identified in 7.6% of the articles, reinforcing the importance of this concept in the approach and management of buildings throughout their life cycle. The analysis of the graph provides a clear view of the predominance of the topics addressed in the selected articles, helping to understand the relevance of each keyword in the research performed.

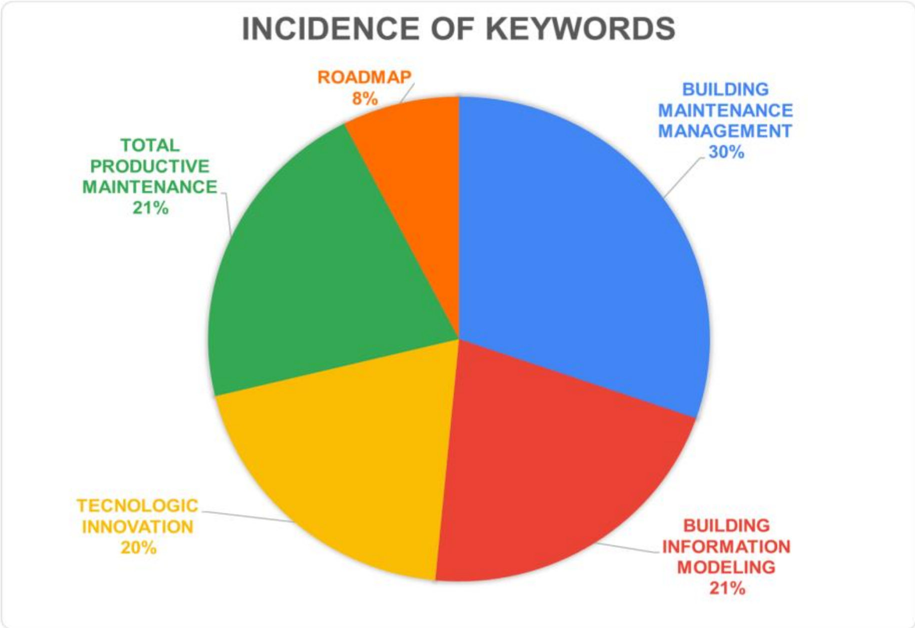

Figure 4 - Incidence of search keywords for selected articles

Technological Roadmap Integrating BIM and TPM

As a measurable result of this research, the technological *Roadmap* was elaborated (Figure 5):

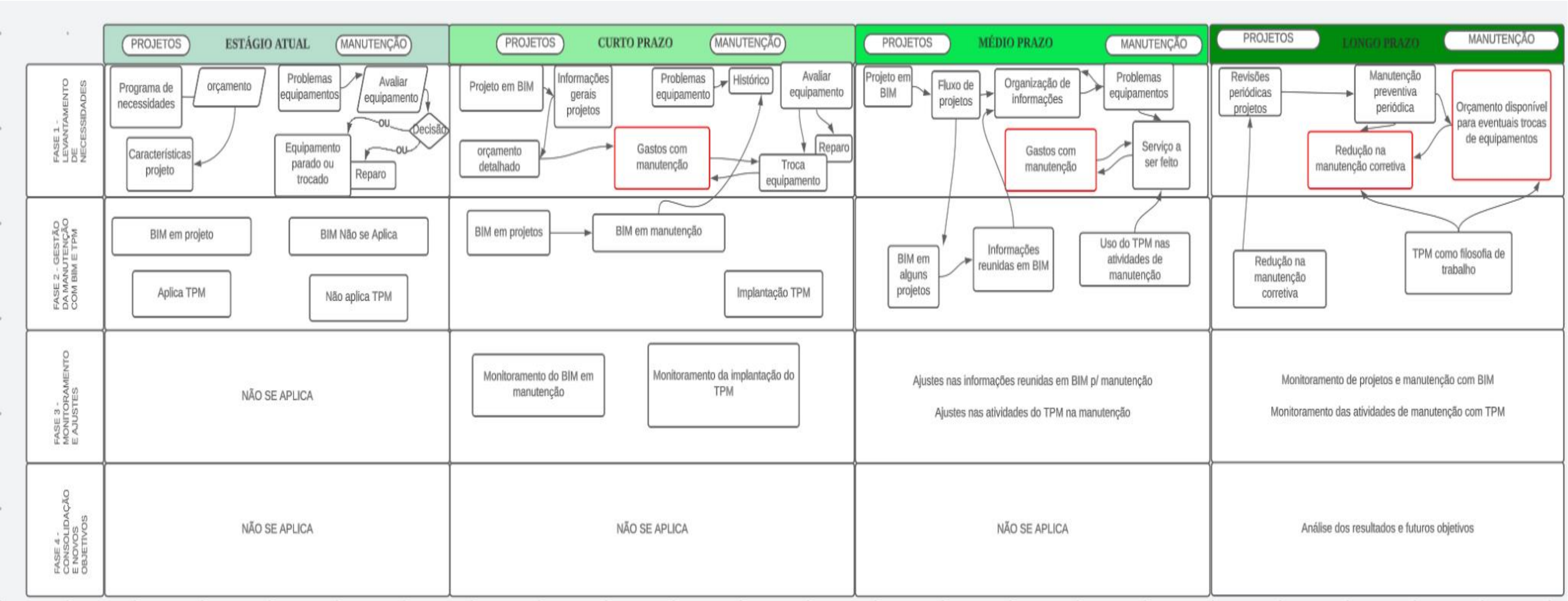

Figure 5 – Technological Roadmap

Phase 1 – Survey of needs and division of teams/tasks: In this phase, the manager must seek all pertinent information about building maintenance (equipment problems, repair time, idle time, budget, and available staff). With this information, the teams and tasks must be separated clearly and precisely, delimiting execution time and providing all the necessary apparatus for accomplishment. Visualising the short, medium and long-term objectives aligned with the proposed objective is necessary.

Phase 2 – Implementation of BIM and TPM: BIM and TPM get implemented in the building maintenance sector in the second phase of this Roadmap. It is in this phase that the manager seeks the acquisition of BIM technology software, as well as training and preparing the team for the use and operation of this technology, in addition to implementing the concepts of the TPM methodology in the daily life of the sector (Material supplementary 3-4).

In the example depicted in Figure 6, post-implementation, the information acquired through the utilisation of BIM technology can apply in assessing program needs, and the concepts of TPM can apply to the work routines in the building maintenance sector.

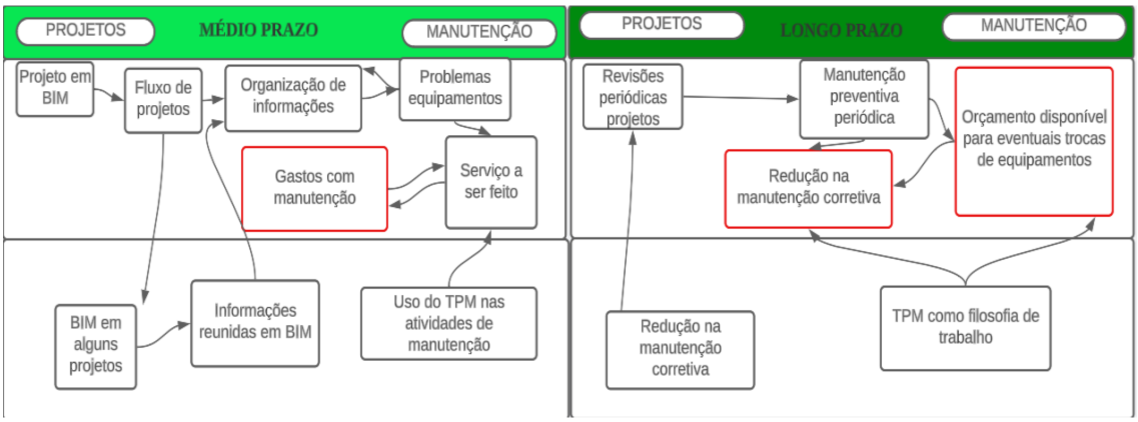

Figure 6 - Use of BIM and TPM after implementation, elaborated by the author.

Phase 3 – Monitoring and adjustments: During the third phase, the manager can perform the monitoring and adjustments. After fulfilling all phases 1 and 2, the manager will evaluate the BIM technology and TPM methodology. They will then make any deemed adjustment, encompassing team reorganisation and task redistribution. Provides suggestions for monitoring and adjusting the use of BIM and TPM in maintenance activities, such as the use of Operating Procedures – POPs, previously elaborated using the concepts of this methodology (Material Supplementary 3-4).

Phase 4 – Consolidation and new objectives: The fourth and concluding phase of this Roadmap involves program consolidation. After phases 1 through 3, the manager will scrutinise the outcomes achieved following all tests and maintenance process adjustments. Based on this evaluation, a decision regarding its effectiveness will occur. If the Roadmap is deemed adequate, it can be considered consolidated. It signifies new objectives and goals. Conversely, reviewing the most challenging aspects is necessary if the Roadmap could be more effective. The initially proposed objectives should undergo evaluation, aiming to implement the necessary adjustments to ensure the process's effectiveness.

Action research using the Technological Roadmap

For the use of the *Roadmap*, a federal university located in Bahia is the object of study. This pilot project lasted 02 months, starting on January 02, 2023, and ending on March 02, 2023, applied in a building already in operation, following the guidelines presented in the *Roadmap.*

PHASE 1: Needs Assessment: To initiate the pilot project, the maintenance sector of the university under study underwent a survey of its main issues. This process led to outlining the initial objectives and establishing the research focus. Initially, the research examined problems in various university sectors like hydraulic, electrical, and air conditioning issues. They selected air conditioning issues for analysis due to the abundance of equipment in the building and the frequent occurrence of problems (Figure 7).

The application began with the research team analysing the history of air conditioning problems since the building's inauguration in July 2021. They collected this data through the HelpDesk® maintenance call system.

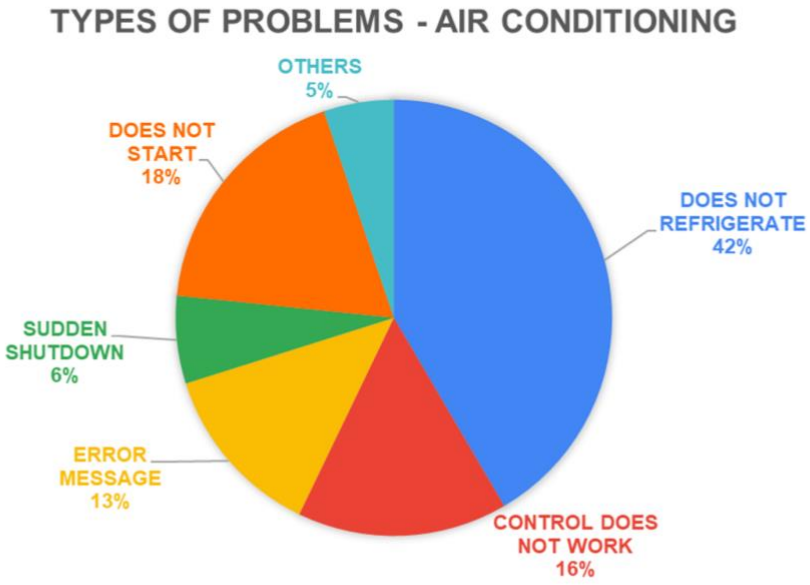

Figure 7 - Percentage of problems presented in the air conditioners evaluated

PHASE 2: Implementation of BIM and TPM

With these data, the proposal involved to use the *usBIM* software to gather information on the air conditioners (manufacturer, location of the appliances, history of problems – Material Supplementary 5 - Table 1), and also the information about the operational procedures of their maintenance (periodicity, necessary staff, instructions for performing the services).

PHASE 3: Monitoring and adjustments

With the *usBIM* software in use and after the adjustments in the operational procedures (with the inclusion of three pillars of the TPM of this operating procedure), the monitoring of the execution of the maintenance services of the air conditioners was carried out, through monitoring in loco of the services and also through the HelpDesk® System verifying if these services and evaluating how the software affected service routine. It is important to note that the *usBIM* software is a cloud organisation tool, which does not allow the elaboration of the three-dimensional plan required by the BIM methodology in a typical data environment that makes collaborative work possible. However, the structural plan of the unit object of study was available and elaborated by the university's team of engineers through the AutoCad® software. In addition, as there was no acquisition of BIM software by the university object of the pilot project, this stage of the Roadmap was not met, but this fact does not preclude the use of the

It was observed in this process that the use of the *usBIM* software was well accepted by the team had access to several files with information about the air conditioners (date of installation, place where each piece of equipment, power, manufacturer, manufacturer's manual), in addition to the operational procedure of air conditioning maintenance (which was already used by the team), that was adjusted, with the insertion of some pillars of the TPM methodology, such as keeping the workplace clean, organised and free of interference (pillar of safety, hygiene and environment), initial verification of the new air conditioners before putting them into use (pillar of initial control) and efficiency and quality tests during preventive maintenance routines (pillar of continuous improvement). From the day of the inauguration of the building (July 29, 2021, to the beginning of the project (January 2, 2023), there were 77 open calls for preventive and corrective maintenance of the air conditioners, where most of these calls received attention after more than 30 days of opening.

During the pilot project, there were 15 calls for preventive and corrective maintenance of air conditioners, and most of these calls received attention within seven days, and all of the calls were within the mark of 30 days for calls. During the period of the pilot project, the maintenance services on the air conditioners were performed using the *usBIM* software to gather the information inherent to the service and also the guidelines of the TPM methodology through the operational procedures. Using the Roadmap as a pillar to manage the information pertinent to building maintenance services – in this case air conditioners, allowed greater control of this information and speed in the execution of services. Additionally, the usBIM software, in conjunction with the HelpDesk resolved issues like challenges in identifying the device-location relationship and the absence of previous service/problem history in the devices.

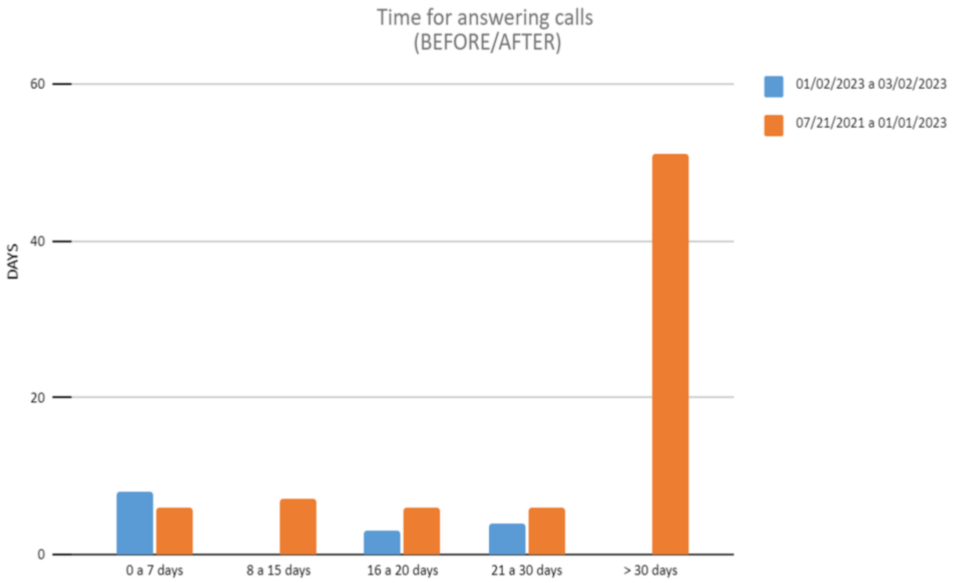

Figure 8 - Call response time before and after the pilot project.

PHASE 4: Consolidation

Following the study period, it became feasible to recognise favourable alterations in the execution of air conditioner maintenance services. These include diminished service durations for maintenance calls and improved organisation of the maintenance team's workspace. These observations substantiate the practical realisation of the proposed Roadmap. Concerning the attained outcomes, the parameter employed was response time for calls. A comparison of this data before and after the pilot project is evident in Figure 8.

5. Discussion

This study presents a technological *roadmap* for managing building maintenance in federal universities, integrating BIM tools and TPM methodology. The research revealed that federal universities need more effective control in building maintenance management, aiming to reduce costs with corrective maintenance and prioritising preventive maintenance. The technological *Roadmap* proposed in this work stands out as a potential tool to meet the need to have a technological tool that assists the building maintenance management sector of universities in the execution of services due to its pre-defined structure, focused on improvements in the short, medium and long term, in line with the principles of BIM and TPM.

The choice for creating and applying this Roadmap stemmed from the scarcity of methods and techniques that gathered the information pertinent to the building maintenance sector, according to the literature review that focused on the building maintenance of universities using BIM and TPM. The pilot project showed that implementing TPM provided greater control in maintenance management, with the potential to reduce corrective problems and, consequently, reduce the execution time of services, contributing to extending the useful life of machinery and equipment.

During the execution of this project, we observed an excellent acceptance of the team involved in managing the university's building maintenance, a positive aspect for applying the Roadmap, according to our initial expectations. However, it is essential to note that the conditions of the two scenarios were different, especially concerning the volume of maintenance calls and the time-lapse. Therefore, the suggestion to continue monitoring persists over an extended duration to validate the ongoing effectiveness of these guidelines.

Cavalcante Filho (2016) studies indicate decreased anomalies in organisation and enhanced inter-sector communication—an aspect also confirmed in this research's project. In addition, the study by Monte (2017) highlighted the acceptance and satisfaction of the TPM associated with the operating procedure. This indicator was also present in the pilot project, evidencing the relevance of this approach for building maintenance management in universities. Similar to previous studies, the results obtained reinforce the relevance of the *Roadmap* developed and the potential it brings to the building maintenance sector. The adoption of TPM allowed to improve communication between sectors, reduced anomalies in the organisation and, in general, improved efficiency in the execution of maintenance services.

6. Conclusion

From these analyses, the technological *Roadmap* integrating BIM and TPM proved promising and consistent with the expectations for managing federal universities' building maintenance. Regarding the limitations of the research, we highlight the need for more access to commercial BIM software since, in the case of a public university, the purchase process involves complex issues, such as bidding and budgeting, which are beyond the reach of the researcher.

Now, it is up to each manager to interest, understand and apply the *Roadmap* in their institution. To support this process, we have provided a primer for applying and using this *Roadmap* as part of the results of this research. In addition, as perspectives, we envision the possibility of conducting additional research to test the application of the *Roadmap* in other institutions and environments, seeking to expand the impact of this approach on the management of building maintenance.

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