Promoting efficiency of building maintenance in public buildings: an approach based on work order records

Promoção da eficiência da manutenção predial em edificações públicas: abordagem baseada em registros de ordens de serviço

Promoción de la eficiencia en el mantenimiento en edificios públicos: un enfoque basado en registros de órdenes de trabajo

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Abstract

Building maintenance activities are instruments to promote sustainability and performance as they support greater durability and efficiency of systems and reduce operating costs. In this research, the profile of the plumbing systems' maintenance work orders from different buildings belonging to a Brazilian public university was evaluated to indicate suggestions for promoting building maintenance efficiency. The research was carried out by analyzing the reports of the buildings' maintenance work orders from a university in the Midwest region of Brazil from 2010 to 2019. Plumbing systems represented 36.48% of all building maintenance demands and 30% of the buildings with the highest incidence of maintenance were newly completed. Buildings up to 5 years old had already consumed approximately 30% of the construction cost with maintenance interventions and had higher maintenance rates than older buildings. Leaks in faucets and blockages in toilet bowls accounted for 26.20% and 23.41% of the records. The propositions in this research support more sustainable implementation of maintenance plans by public managers and validate actions aimed at improving the project design, work execution, inspection stages and approval of similar buildings.
Keywords: *Building maintenance, Plumbing systems, Building pathologies, Sustainable construction.*

Resumo

As atividades de manutenção predial são instrumentos de promoção de sustentabilidade e desempenho à medida que favorecem maior durabilidade e eficiência dos sistemas e reduzem os custos operacionais. Nesta pesquisa, o perfil das ordens de serviço de manutenção dos sistemas prediais hidrossanitários de diferentes edificações pertencentes a uma universidade pública brasileira foi avaliado com a finalidade de indicar sugestões para promover a eficiência da manutenção predial. A pesquisa foi realizada através da análise de relatórios de ordens de serviço de manutenção de uma universidade da região Centro-Oeste do Brasil entre os anos de 2010 e 2019. Os sistemas hidrossanitários representaram 36,48% de todas as demandas de manutenção predial e 30% das edificações com maior incidência de manutenção eram recém concluídas. Edifícios com até 5 anos de uso já haviam consumido aproximadamente 30% do custo de construção com manutenções e apresentaram índices de manutenção maiores que edifícios mais antigos. Vazamentos em torneiras e entupimentos em bacias sanitárias representaram 26,20% e 23,41% dos registros. As proposições desta pesquisa subsidiam a implantação mais sustentável de planos de manutenção por gestores públicos e validam ações que visam a melhoria das etapas de projetos, execução, fiscalização e recebimento de obras similares.
Palavras-Chave: Manutenção predial, sistemas prediais hidrossanitários, manifestações patológicas prediais, sustentabilidade.

Resumen

Las actividades de mantenimiento de edificios son instrumentos para promover la sostenibilidad y el desempeño, ya que favorecen una mayor durabilidad y eficiencia de los sistemas y reducen los costos de operación. En esta investigación, se evaluó el perfil de las órdenes de servicio para el mantenimiento de los sistemas hidrosanitarios edilicios de diferentes edificios pertenecientes a una universidad pública brasileña con el fin de indicar sugerencias para promover la eficiencia del mantenimiento de los edificios. La investigación se llevó a cabo a través del análisis de los informes de órdenes de servicio de mantenimiento de una universidad de la región Medio Oeste de Brasil entre los años 2010 y 2019. Los sistemas hidrosanitarios representaron el 36,48 % de todas las demandas de mantenimiento de edificios y el 30 % de los edificios con mayor incidencia de mantenimiento. se completaron recientemente. Los edificios con hasta 5 años de uso ya habían consumido aproximadamente el 30 % del costo de construcción con mantenimiento y tenían tasas de mantenimiento más altas que los edificios más antiguos. Las fugas en grifos y taponamientos en sanitarios representaron el 26,20% y el 23,41% de los registros. Las propuestas de esta investigación subsidian la implementación más sostenible de los planes de mantenimiento por parte de los gestores públicos y validan acciones que tienen como objetivo mejorar las etapas de proyectos, ejecución, inspección y recepción de obras similares.
Palabras clave: *Mantenimiento de edificios, Sistemas hidrosanitarios de edificios, Manifestaciones patológicas de los edificios, sostenibilidad.*

1. Introduction

According to ISO 15686-1 (2011) and the NBR 5674 (ABNT, 2012), building maintenance is defined as any interventions carried out in the systems, elements, and constituent parts of a building, throughout its service life, to provide the correct functioning and performance of the installations. Maintenance procedures aim to maintain pre-established performance levels in a project (MORAIS *et al.*, 2019), maximize the service life of the building (NÄGELI *et al.*, 2019) aiming to delay the occurrence of failures and deterioration of building systems (FERREIRA *et al.*, 2021). The existence of an active and efficient maintenance plan is essential for those facilities to meet the required functions, purposes, and objectives of the project, especially regarding public buildings (MORAIS *et al.*, 2019; HASSANAIN *et al.*, 2019).

Therefore, maintenance must be treated as an activity with a continuous and regular characteristic, it must be carried out with planning, organization, direction, and control of resources (LATEEF, 2010). To improve the execution of maintenance activities, it is important to understand all the variables that may affect the building systems over the years, such as the durability and the life cycle of the elements (FARAHANI *et al.*, 2019), the natural phenomena of aging and wearing of parts (SILVA *et al.*, 2019) and the behavior of users towards the facilities (MORAIS *et al.*, 2019).

In public universities, building maintenance activities are especially important. Therefore, there is a correlation between the quality of the university's facilities and the effectiveness of learning, academic performance, user actions, and the motivational state of professors and students who are affected by the conservation condition of such buildings (ABDULLAH *et al.*, 2021). It is necessary and important to carry out satisfactory maintenance in universities; any failure to perform these services, in addition to representing a loss of value for the building, causes damage to the entire university community and also to the institution's image (LATEEF *et al.*, 2010).

For Khalid *et al.* (2019), the lack of building maintenance is a problem that affects mainly developing countries. While in developed nations such as the United Kingdom and Italy, maintenance works are instruments for promoting sustainability, adding durability and value to construction elements (MARTINAITIS *et al.*, 2004), in emerging countries, such as Malaysia and Saudi Arabia, these practices are still being consolidated, don't receive due importance and need to be improved, especially in public buildings.

In Malaysia, universities were mostly built in the 1960s and suffer from the wear and tear of time. This deterioration was exacerbated by factors such as the low quality of the materials used, inadequate level of finishing, excessive use and poor maintenance (LATEEF, 2010).

According to Hassanain *et al.* (2019), in Saudi Arabia, there was great growth in investment in higher education followed by an increase in the physical structure of universities, but it is common to lack maintenance plans in public university facilities.

According to Lateef (2010), public universities in emerging nations focus their activities on corrective maintenance because of the imposed budget limits, use of low-quality materials, and often undersized and disqualified teams. Persistent budget constraints are observed in these countries, even with significant growth in the physical structure of public universities (EBEKOZIEN *et al.*, 2021). Based on this phenomenon, there is a large increase in building maintenance demands, which are generally increasingly onerous over the years (SANDANAYAKE *et al.*, 2020), which makes this process increasingly less sustainable (RUPARATHNA *et al.* 2018).

Brazil, a large country that has the economic characteristics of a developing nation, has its particularities in the higher education system. The first universities were only built in 1808 (MELO, 2011). In 1998, it had one of the worst access rates to higher education in Latin America (FAVATO e RUIZ, 2018).

To compensate for Brazil's historical educational delay and to expand the conditions of access and permanence in higher education by public policies, the Program for Restructuring and Expansion of Federal Universities (*Restruturação e Expansão das Universidades Federais*, in Portuguese) was instituted, named REUNI, proposed by the federal government in 2007 (FAVATO e RUIZ, 2018). Since this program was implemented, there has been a large increase in the number of municipalities served by universities and a notable growth in the number of enrollments. (SALLES *et al.*, 2020). In addition, there has been a great increase in the physical structure (built-up area) throughout the expansion period (LIMA *et al.*, 2016).

Currently, there is an advancement in the service life of the REUNI buildings along with significant participation in the university building maintenance process (PRADO, 2017).

Despite the consensus that the expansion of the physical structure of universities requires increased future investments in building maintenance, in Brazil universities face a lack of financial resources for building maintenance and the inefficient management of available resources (NETO, 2015). Brazilian legislation favors the selection of suppliers and contractors based only on the lowest price criterion, disregarding quality. All these factors make maintenance activities slow and of low quality, becoming a barrier to achieving sustainability and efficiency in the operation of public buildings (AU-YONG *et al.*, 2022).

Building systems represent most of the maintenance and upkeep demands of Brazilian public universities (PRADO, 2017). In this context, several authors indicate that the plumbing systems are among those with the highest number of requests for technical assistance in the period of use and operation of a building, with high percentages about the total number of maintenance demands — 17.75% as observed by Morais and Lordsleem (2019), 25% by Sandanayake *et al.* (2020) and 49.62% by Prado (2017).

According to Conceição (2007), after the construction, the plumbing systems are among those that suffer the most requests due to direct interaction with users´ needs. Furthermore, these systems have peculiar characteristics such as the heterogeneity of their components and also the dynamic interrelationship between their subsystems, thus presenting a particular complexity (ILHA, 2009). Prado (2017) indicates that adversities in plumbing systems are characterized by events in occurrence and with an evolutionary trend, that is, they can worsen over time and cause enormous financial losses if not corrected.

Despite the significance of building maintenance procedures and the representativeness of plumbing systems within these demands, importance is not given to the study and analysis of the performance of these systems during the use and operation of buildings. In this context, Carretero-Ayuso *et al.* (2019) indicate that the publications that specifically deal with failures and defects in plumbing systems are minimal, which leads to the lack of knowledge of the causes of these anomalies and the repetition of the same errors in different projects, causing, in turn, a high incidence of demands for the maintenance of these systems.

Moreover, most studies that aim to evaluate building maintenance systems are based on questionnaires directed to users and professionals in the area or by the survey of registered complaints by users. As a differential, this paper analyzed maintenance work order records, evaluated and generated by technicians and building managers. No assessments were found in the literature specifically aimed at the performance of plumbing systems in the use and operation stage of buildings that used the institution's maintenance records as a database.

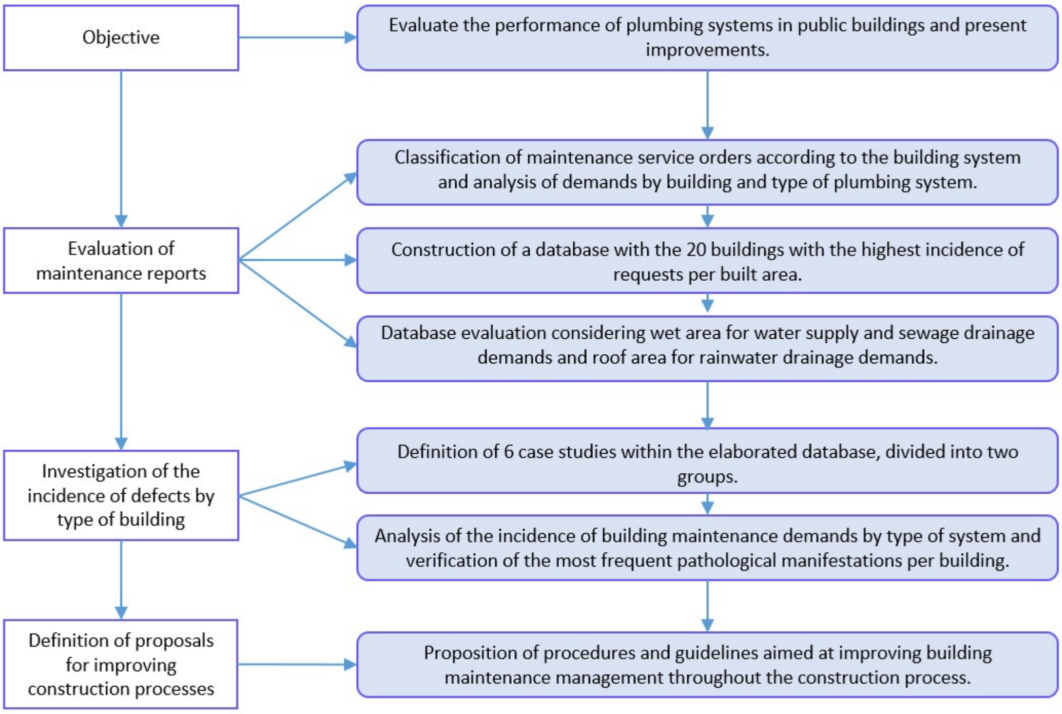
Thus, this study evaluates the records of maintenance work orders for buildings of different ages and purposes of a public university in the Midwest region of Brazil, to observe the profile of corrective measures occurring in the plumbing systems and their financial impact, contributing to the proposition of procedures to develop more durable projects and practices to improve the efficiency in the in building maintenance management.

2. Methodology

This study was carried out at the Federal University of Goiás (UFG) in buildings located in the city of Goiânia, the state of Goiás - Brazil. The institution was chosen to develop the research due to the availability and reliability of documents and electronic databases, essential for carrying out the surveys. UFG's buildings have very specific and diverse characteristics, such as locations, construction technologies, ages and types.

Fig. 1 shows the flowchart of the development of research activities, which initially included the search, selection and categorization of a large volume of data regarding all building maintenance work orders registered from 2010 to 2019.

Figure 1: The methodology adopted in this study.



1.1. Evaluation of building maintenance reports

To assess the relationship between maintenance requests and the institution's built-up area over the years, the parameter of the number of work orders per 100 m² was adopted — adapted from Morais and Lordsleem (2019) — according to Equation 1:

$$n^{o}\ of\ work\ orders\ per\ 100\ m^{2} = \frac{total\ work\ orders}{accumulated\ built - up\ area}\ x\ 100 \qquad (1)$$

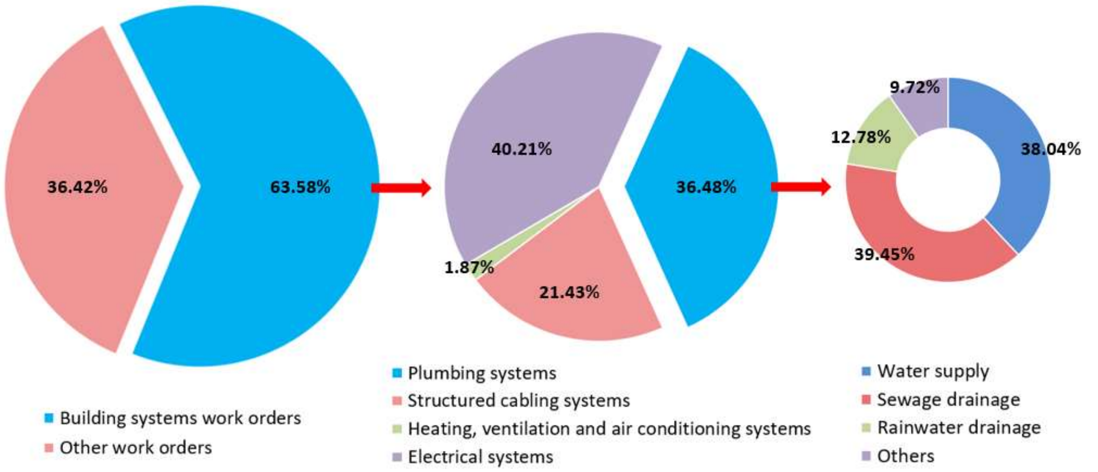
Table 1 shows the growth of the built-up area in the institution and the number of maintenance work orders registered during the study period, in which there was a trend of growth in the number of building maintenance requests per 100 m² of built-up area and the incorporation of new buildings into the university's physical structure over the years.

Table 1: Annual evolution of the accumulated built-up area and building maintenance requests in absolute numbers and per 100 m² of built-up area.

Year	Accumulated built-up area (m²)	Total work orders	Number of work orders per 100 m²
2010	211,016.94	8,817	4.178
2011	229,415.09	8,413	3.667
2012	266,440.34	9,464	3.552
2013	277,761.45	11,918	4.291
2014	286,063.43	12,029	4.205
2015	291,230.53	12,659	4.347
2016	291,610.15	13,048	4.474
2017	300,352.81	13,635	4.540
2018	303,033.74	13,044	4.304
2019	306,083.01	11,929	3.897

The classification of work orders started after collecting the maintenance reports. As shown in Fig. 2, the data classification was firstly based on the categorization of work orders referring to building systems, which had average participation of 63.58% during the period evaluated. Afterward, these records were separated by type of building system. At this stage, an average of 36.48% of the building maintenance work orders were related to plumbing systems, corroborating with the high percentages found in the literature. The work orders referring to plumbing systems were then categorized according to the type of plumbing system.

Figure 2: Percentage of maintenance records by building system typology during the evaluated period (2010 to 2019).



The university buildings were cataloged to assess the incidence of maintenance per building. In 2019, 175 buildings were verified as objects of study. Then, work orders were classified and cataloged by the building in which the maintenance service was performed. Due to the large number of buildings found in the institution, a database was built with the 20 buildings with the highest incidence of work orders per 100 m² of built area.

Fig. 3 shows the percentage of built area and number of work orders that the 20 selected buildings represented to the total surveyed. Notably, the representative percentage of the number of work orders of these buildings corresponds to values well above the percentage of the built-up area of the group, and in most years the percentage of the number of work orders is presented as double the proportional built-up area, demonstrating the representativeness of this sample within the study.

Figure 3: Comparison of the percentage share between the number of work orders and the constructed area of the studied building group.

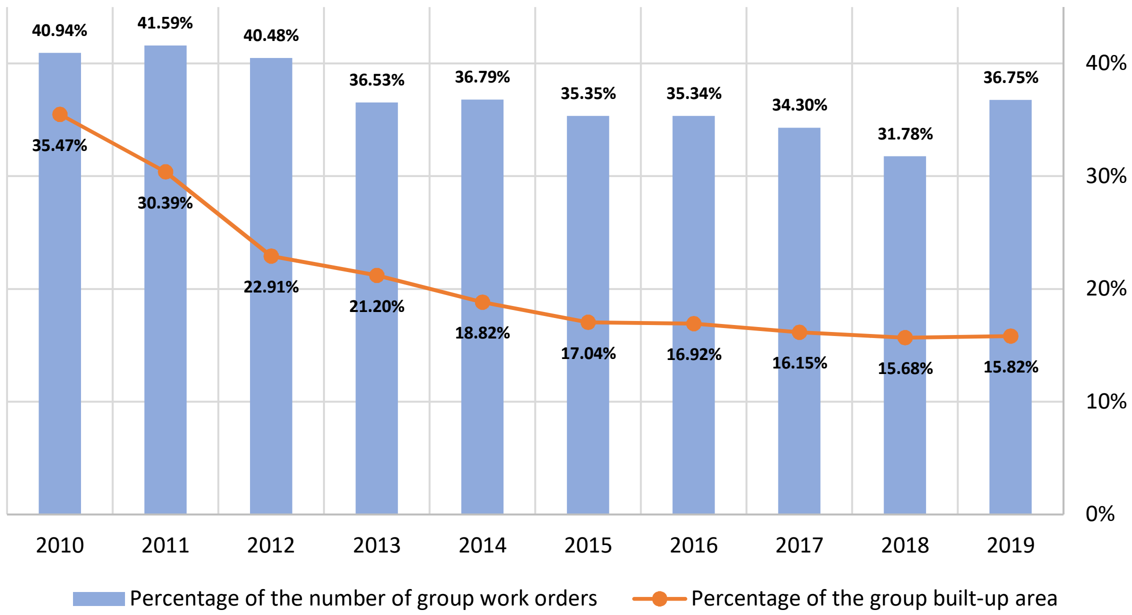
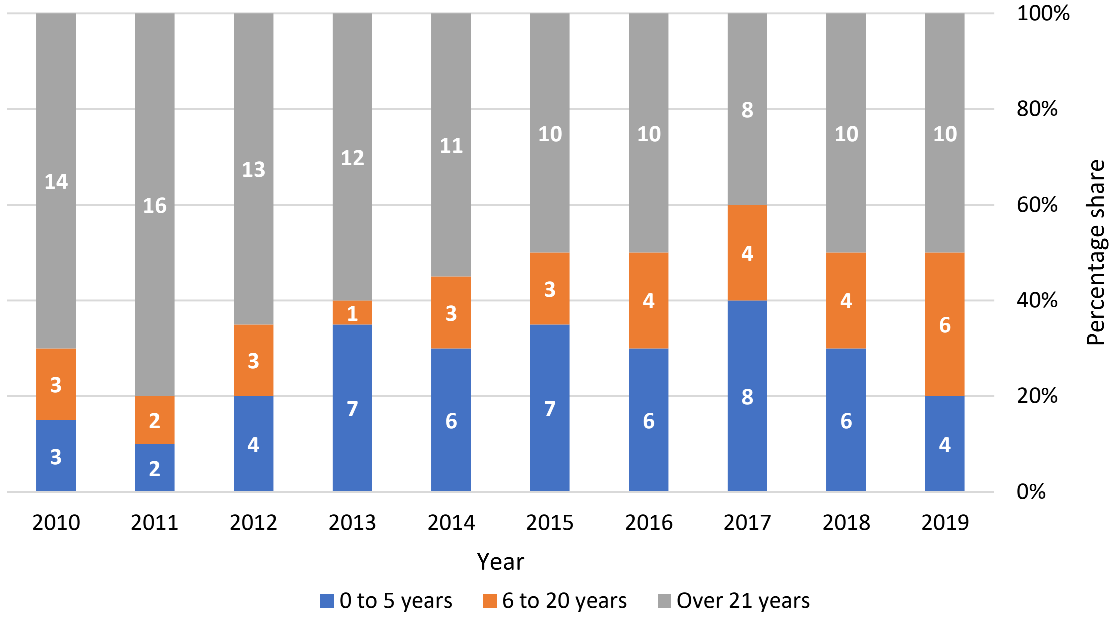


Fig. 4 shows the age ranges of these 20 buildings. During the period from 2013 to 2018, buildings aged 0 to 5 years represented more than 30% of all buildings, especially in 2017, when these new buildings represented 40% of the total. As of 2018, there was an increase in the number of buildings aged over 6 years, which can be explained by the decline of new constructions from that year onwards and the increase in the age of the existing buildings.

Figure 4: Age ranges of the group's buildings.



From this reduced database, a new evaluation was carried out differentiating the buildings according to the type of plumbing system. Considering the comparative parameter of the number of work orders per 100 m², for the work order records referring to the water supply and the sewage drainage systems the total built-up area was replaced by the wet area, such as bathrooms, sculleries, service areas, and laboratories. The building's roof area was used for the evaluation parameter of the rainwater drainage system work order records. This form of assessment made it possible to analyze the incidence in a different way for each type of plumbing system considered.

1.2. Investigation of incident pathological manifestations (faults) by building

To enable a more in-depth study of the incidence of defects and failures in the plumbing systems at a building level, as well as to verify which were the most frequent types of pathological manifestations and maintenance demands, six buildings were selected with age ranges that represented, during 2019, the same proportion of age ranges verified in the 20 buildings sample for that same year, as shown in Fig. 4.

These buildings were separated into two groups according to data analysis:

First Group: it comprised three buildings with its completion year within the data analysis period (2010 to 2019). The incidence of building maintenance work orders was observed over the 5 years following the beginning of use and occupation of these buildings, considering the new parameters adopted: number of work orders per 100 m² of wet area for the records of water supply and sewage drainage systems and number of work orders per 100 m² of roof area for the rainwater drainage system records. An analysis of the types of failures and defects reported for each building was carried out to observe the most common type of pathological manifestations.

Second Group: comprising three buildings with starting dates of use and operation before the survey of this study. As these buildings had more advanced ages during the analysis period (Table 2), the adopted interval for data evaluation was from 2015 to 2019. Over the years, the incidence of building maintenance requests was observed as a function of the established parameters, evaluating the types and levels of pathological manifestations occurrence reported for each building.

Table 2: Buildings selected for the study were divided into two groups.

Group	Building	Use and operation start year	Age range in 2019	Predominant typology of use
1	Classroom Block D	2012	0 to 5 years	Multidisciplinary classrooms
	Takinahaky Nucleus	2012	6 to 20 years	Research and Extension
	Faculty of Pharmacy	2014	6 to 20 years	Research and Extension
2	Tropical Pathology and Public Health Institute (TPPHI)	1988	Over 20 years	Research
	Central Library	1988	Over 20 years	Library
	Faculty of Dentistry	1989	Over 20 years	Research and Extension

2.3 Assessment of the financial impact of maintenance activities

Based on the analysis of maintenance demands incident in each building, labor and material costs were assigned for each service considered, through the adaptation of unit cost compositions of GOINFRA (Goiana Agency of Infrastructure and Transport) and SINAPI (National System for Research on Civil Construction Costs and Indexes), official Brazilian government databases used as a reference for public construction cost compositions. For the calculation of labor costs, the average hourly cost of displacement of the team, evaluation, testing, and repair or replacement of the component was considered. For the material consumption index calculation, the average incidence of repair or complete replacement of the element, verified in the evaluated database, was considered by type of service. To estimate the cost of each maintenance service, the reference date of January 3, 2022, was considered and the values obtained were converted from Brazilian real to US dollar (1 US dollar ≅ 5.63 Brazilian real). Based on these compositions, the financial cost of maintenance was estimated that each building would pay annually if all maintenance work orders were executed.

Finally, the estimated amount of the maintenance services of each building was compared with its initial cost of executing the plumbing systems, extracted from the contractual budget, updated to the same base date as the maintenance compositions (January 03, 2022) through the INCC-M (National Construction Cost Index - Market), the official index used in Brazil to calculate the monthly variation in construction prices.

The assessment of the financial impact of maintenance activities was performed only for the buildings in Group 1, buildings in which budget data were available. For the buildings in Group 2, as they are older, contractual documents were not found with the initial costs of construction of these buildings.

This comparison made it possible to verify the financial impact of maintenance activities in the buildings of Group 1 immediately after the start of use and operation of the systems, that is, in the period in which the building is considered "newly completed".

2.4 Proposals for improving the construction processes

Based on the analyses and assessments carried out on the incidence of pathological manifestations (faults) and the financial impact of maintenance activities, actions were proposed to be implemented in the design stage and guidelines were recommended for improving the maintenance management of public buildings, which can be replicated in public agencies with similar buildings, mainly in developing countries, improving existing construction and maintenance standards.

3. Results

Data evaluation for each building made it possible to verify the incidence of maintenance in the plumbing systems considering the specific characteristics of each construction. Figures 6 and 7 show the temporal evolution of the number of maintenance work orders in water supply and sewage drainage (Fig. 6) and in rainwater drainage (Fig. 7) systems for the buildings in Group 1, in which the annual index of maintenance in the first five years of use and operation was evaluated.

In this group, there was a high incidence of maintenance demands in buildings immediately after completion of the construction, a phenomenon also observed by Hopkin *et al.* (2017) and Abdullah *et al.* (2021), which indicated the high share of newly completed buildings in existing maintenance systems.

Figure 5: Temporal evolution of the number of maintenance work orders in the water supply and sewage drainage systems per 100 m² of the wet area in Group 1 buildings.

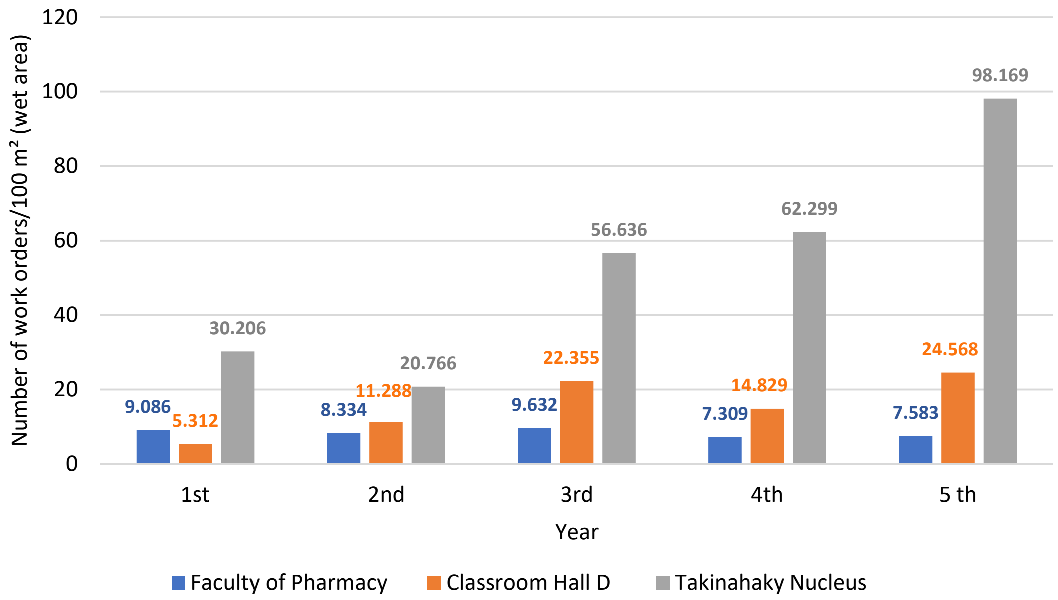
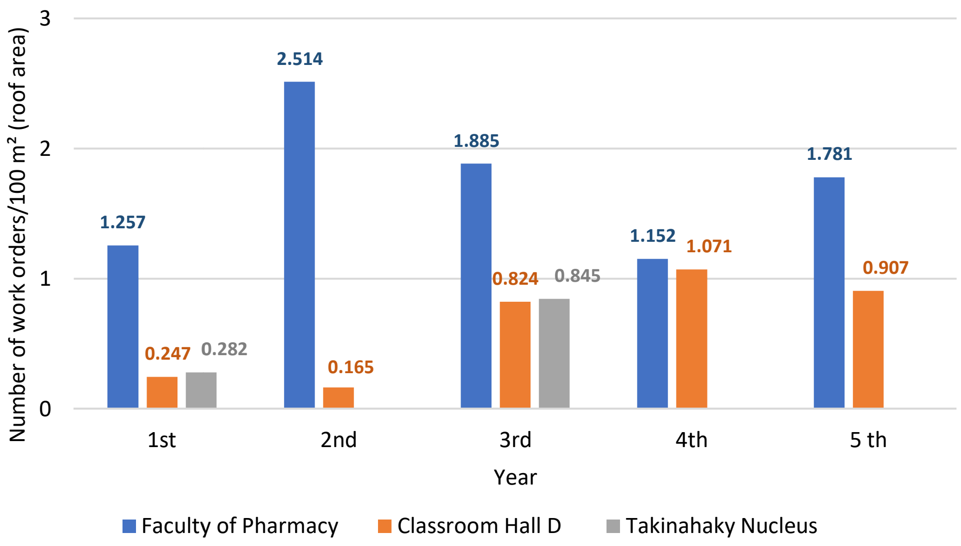


Figure 6: Temporal evolution of the number of maintenance work orders in rainwater systems per 100m² of roof area in Group 1 of buildings.



Tables 3–5 discriminate the types of maintenance records observed for the buildings in Group 1. High rates of demand records of maintenance are registered already in the first and second year after the effective use, which would not be expected for newly completed buildings (HOPKIN *et al.*, 2017).

The work orders regarding the Faculty of Pharmacy building are characterized by the variety and diversity of elements and components affected, recording different types of defects and failures, such as leaks, clogging, infiltration, and detachment of parts. This discards the hypothesis of a deficiency of only one type of component or system and may indicate the general use of low-quality materials or low quality of work execution, due to the contracting conditions of the building's construction, as indicated by Morais and Lordsleem (2019) and Ferreira (2021). In this building, the demands referring to leaks and defects in faucets and storage tanks had been decreasing over the years. As no major interventions were identified during this period, it can be assumed that maintenance activities—such as replacing components and carrying out repairs to the facilities—were correcting defects in these elements or replacing low-quality materials used, a phenomenon also observed by Hassanain *et al.* (2019) in university buildings in Saudi Arabia; in which maintenance, during the period of use and operation, is involuntarily assigned to repairing faults arising from the design and execution stages of the building.

Regarding the sewage drainage system, high incidences of blockages in several components were verified in the first year of use of the building, as well as reports of odor returning inside some rooms. Considering the short time of the system's use, it is likely that debris and residues from the work execution may have caused these blockages, which indicates how the poor quality of the construction services and workmanship can influence the future maintenance of the building, as reported by Sandanayake *et al.* (2021).

Several work orders related to equipment installations were observed, the object of which are adjustments in water supply and sewage drainage facilities to enable the installation of drinking fountains (Fig. 7b) and equipment in laboratories. These requests indicate the absence of planning requirements for the use of the building and the lack of forecast of specific points for these pieces of equipment in the design phase, requiring further adaptation to install these elements. These interventions could be avoided if this equipment had been foreseen in the project, characterizing a need to improve the design stage and preliminary studies of the needs of the building and the facilities, as already indicated by Hassanain *et al.* (2019) and Khalid *et al.* (2019).

Detachment of washbasins and toilet bowls (Fig. 7a) is also noteworthy, which are defects that should be related to the natural aging of an installation, but which were reported in the buildings. The incidence of these failures, in the first years of use and operation of a building, may be related to poor execution of the fixing of these elements during the construction stage, indicating deficiencies in this phase of the building, which is also observed by several authors in different countries, such as Morais and Lordsleem (2019), Lateef *et al.* (2010), Hassanain *et al.* (2019) and Abdullah *et al.* (2021).

Concerning Classroom Block D, there are recurring records in maintenance demands related to flooding on the basement floor and in the elevator shaft (Table 05), which has been a problem during intense rain events. This problem can be caused due to design flaws in the interconnection of conductors, drains, and inspection chambers; in addition to the under-dimensioning of the rainwater drainage system or lack of maintenance of these elements.

At the Takinahaky Nucleus, most of the work orders were related to the water supply system with a share of more than 50% in all years (Table 03) (Fig. 7c). As of the third year of use of this building, there was an abrupt increase in maintenance demands on this system. Considering the relatively short time of use of these facilities, it can be assumed that deficiencies occurred in the design stages (solutions adopted) and work execution (use of low-quality materials or poor execution), influencing the incidence of these defects and failures in the building.

The high incidence of repairs related to leakage and blockage of siphons (p-trap) is also noteworthy (Table 4). Corrugated plastic siphons, commonly used in the evaluated buildings (Fig. 7d), have limited durability, as they tend to wear out more quickly, mainly due to dryness from exposure to cleaning products and microorganisms. In this case, the specification should be made during the design stage for the use of more resistant metal or rigid PVC siphons, with a threaded and removable body (bottle trap); providing easier cleaning and unclogging, as well as greater durability, which would result in the reduction of these pathological manifestations and repair costs.

Figure 7: Pathological manifestations verified in the building maintenance records: (a) washbasin detachment, (b) adaptations in drinking fountains facilities, (c) blockage of toilet bowls and (d) corrugated siphon dried (d).

(a) (b) (c) (d)

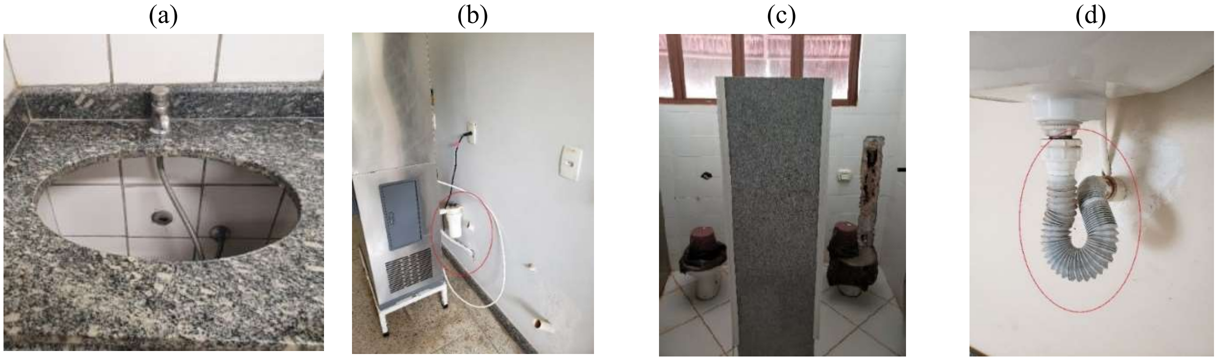


Table 3: Maintenance records reported in Group 1 buildings for the water supply building system.

Building	FACULTY OF PHARMACY						CLASSROOM BLOCK D						TAKINAHAKY NUCLEUS					
Water supply	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**
Installation and maintenance of drinking fountains or equipment	11	10	6	7	2	12.12%	4	4	2	2	3	12.00%	2	-	-	1	3	6.25%
Leaks and defects in faucets	21	25	20	12	11	29.97%	2	-	-	2	5	7.20%	-	-	-	11	7	18.75%
Leaks and defects in flush valves	6	10	11	8	13	16.16%	2	1	15	8	13	31.20%	-	1	-	5	8	14.58%
Leaks and failures in storage tanks	12	6	8	6	9	13.80%	2	-	7	6	4	15.20%	-	-	2	4	1	7.29%
Lack of water or inadequate pressure	7	2	10	2	-	7.07%	-	11	4	1	10	20.8%	-	1	2	-	-	3.12%
Leaks in pipes or faucet supply line	4	11	10	9	15	16.50%	-	2	7	3	5	13.60%	4	2	16	6	17	46.88%
Leaks and defects in valves	4	-	8	-	1	4.38%	-	-	-	-	-	0.00%	-	-	-	2	1	3.13%
Total	65	64	73	44	51	297	10	18	35	22	40	125	6	4	20	29	37	96
Annual Percentage for plumbing systems	46.43%	51.61%	48.99%	41.12%	41.46%	-	29.41%	33.33%	33.02%	28.21%	36.04%	-	50.00%	80.00%	83.33%	80.56%	75.51%	-

Table 4: Maintenance records reported in Group 1 buildings for the sewage drainage building system.

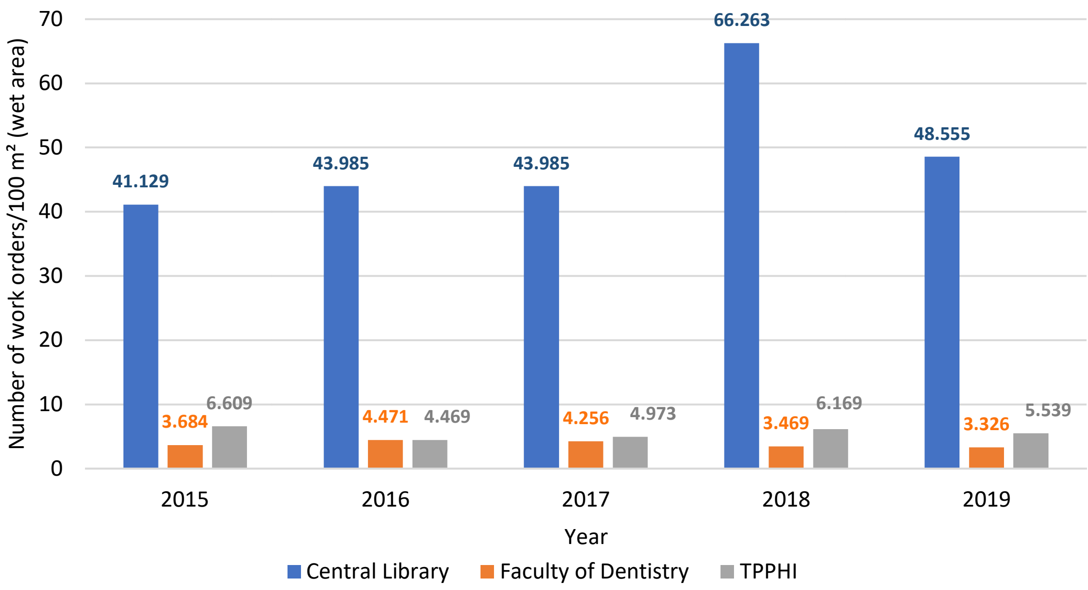
Building	FACULTY OF PHARMACY						CLASSROOM BLOCK D						TAKINAHAKY NUCLEUS					
Sewage drainage	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**
Installation and maintenance of drinking fountains or equipment	10	-	2	7	2	7.90%	8	10	10	2	2	14.48%	3	-	1	1	1	23.08%
Blockage or leaks and defects in siphons	13	16	10	12	16	25.19%	2	4	8	5	9	12.66%	-	-	-	6	-	23.08%
Blockage in toilet bowls	14	2	9	16	6	17.67%	3	12	20	20	17	32.58%	-	-	-	-	3	11.54%
Blockage in floor drains	6	7	22	12	8	20.68%	5	4	15	11	6	18.55%	-	-	-	-	-	0.00%
Returns of odor	7	4	3	-	2	6.02%	-	-	-	-	-	0.00%	-	-	-	-	-	0.00%
Washbasin or toilet bowl detachment	9	6	10	1	4	11.28%	-	2	-	-	3	2.26%	-	-	-	-	1	3.85%
Leaks in pipes	5	1	1	3	7	6.39%	2	1	1	1	3	3.62%	2	1	-	-	7	38.46%
Blockage in urinals	-	-	2	1	10	4.89%	-	1	1	5	15	9.95%	-	-	-	-	-	0.00%
Damaged toilet seat	-	-	-	-	-	0.00%	1	-	6	-	6	5.88%	-	-	-	-	-	0.00%
Total	64	36	59	52	55	266	21	34	61	44	61	221	5	1	1	7	12	26
Annual Percentage for plumbing systems	45.71%	29.03%	39.60%	48.60%	44.72%	-	61.76%	62.96%	57.55%	56.41%	54.95%	-	41.67%	20.00%	4.17%	19.44%	24.49%	-

Table 5: Maintenance records reported in Group 1 buildings for the rainwater drainage building system.

Building	FACULTY OF PHARMACY						CLASSROOM BLOCK D						TAKINAHAKY NUCLEUS					
Rainwater drainage	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**	**1st year**	**2nd year**	**3rd year**	**4th year**	**5th year**	**%**
Leaks and clogging in gutters	1	4	4	3	4	20.00%	-	-	1	3	6	27.03%	-	-	-	-	-	0.00%
Occurrence of infiltrations	10	19	10	6	11	70.00%	-	-	-	-	-	0.00%	1	-	3	-	-	100.00%
Roof maintenance requests	-	1	3	2	2	10.00%	-	-	-	-	-	0.00%	-	-	-	-	-	0.00%
Elevator shaft or basement floor flooding	-	-	-	-	-	0.00%	3	2	9	9	4	72.98%	-	-	-	-	-	0.00%
Total	11	24	17	11	17	80	3	2	10	12	10	37	1	0	3	0	0	4
Annual Percentage for plumbing systems	7.86%	19.35%	11.41%	10.28%	13.82%	-	8.82%	3.70%	9.43%	15.38%	9.01%	-	8.33%	0.00%	12.50%	0.00%	0.00%	-

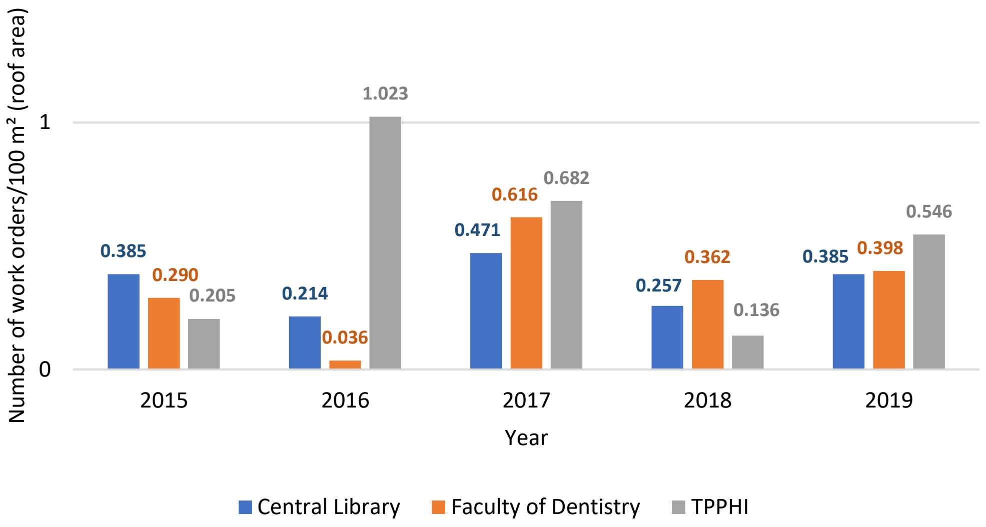
For the buildings in Group 2, Fig. 8 shows the indexes of maintenance work orders per 100 m² of wet area for the water supply and sewage drainage systems; and Fig. 9, for the rainwater drainage system. In the Central Library building, maintenance rates for the water supply and sewage drainage systems were higher than 40 work orders per 100 m² of wet area throughout the period. Notably, the Central Library building is intensively used, serving a wide academic community and having a small wet area to the total built-up area, unlike the buildings of the Faculty of Dentistry and the Tropical Pathology and Public Health Institute (TPPHI), which are geared towards research activities, focused on a specific public and have a larger wet area to the total built-up area. Lateef (2010) reports that the intense use of a building can directly affect the higher incidence of failures and defects in the facilities, indicating that the designs for buildings with this typology should be prepared considering these factors, adopting specific and more durable materials, with solutions that allow easier access and maintenance. Likewise, in the use and operation stage, the maintenance plans of these buildings must receive special treatment, observing these characteristics (ISMAIL, 2021).

Figure 8: Temporal evolution of the number of maintenance work orders in the water supply and sewage drainage systems per 100 m² of the wet area in Group 2 of buildings.



Analyzing Group 2, an irregular behavior was found in the maintenance indexes of the rainwater drainage system (Fig. 9). After evaluating the descriptions of the services contained in these maintenance work orders, it was observed a high number of reworks in the interventions carried out. This problem was associated with the use of low-quality materials or precarious improvisations due to the lack of specific material for the repair, both situations were also indicated by Hassanain *et al.* (2019) and Abdullah *et al.* (2021) in Malaysia and Saudi Arabia, respectively. That is a fact that worsens the quality and performance of buildings in the long term.

Figure 9: Temporal evolution of the number of maintenance work orders in rainwater systems per 100m² of roof area in Group 2 of buildings.



Tables 6–8 show the survey of the profile of records for building maintenance and the pathological manifestations verified for the buildings in Group 2. In these buildings aged above 20 years, a high incidence of leakage was observed in faucets and flush valves (Table 6). These system components are the ones that most receive direct requests from users, corroborating the statements by Teixeira *et al.* (2011), who indicated that the direct interaction with users—occurring in diverse ways—makes the plumbing system one of the biggest demands from building maintenance. There were several reports from the TPPHI building of leaks in water storage tanks; and from the Central Library, a lack of water in the supply system. These problems were repeatedly reported over the years and have a chronic and complex solution; indicating technical limitations of the institution's maintenance team, such as a lack of materials, adequate equipment, tools, or workmanship qualified for the service, all of which were indicated by several authors as common limitations in building maintenance systems in developing countries (LATEEF *et al.*; 2010; HASSANAIN *et al.*, 2019; ABDULLAH *et al.*, 2021).

Analyzing the work orders related to the sewage drainage system (Table 7), the blockage of siphons, toilet bowls, floor drains and leaks in siphons stood out as the most reported pathological manifestations. These defects can be related to heavy and sometimes inappropriate use (TEIXEIRA *et al.*, 2011; LATEEF, 2010). As early as the design stage, attention should be paid to the foreseen usage demands according to the building typology, for a more adequate specification of its components and a correct dimensioning of the sections and slopes of the pipes, and also for a careful definition of maintenance actions of these system components.

For the rainwater drainage system (Table 8), there are reports of infiltration and leaks in the roof systems of the three buildings. The "roof maintenance requests" work orders come from user demands to carry out maintenance procedures on the roofs, which indicates the lack of preventive and predictive actions by the institution's maintenance management team before the rainy season, characteristic of the region.

Table 6: Maintenance records in Group 2 buildings for the water supply building system.

Building	TPPHI						CENTRAL LIBRARY						FACULTY OF DENTISTRY					
Water supply	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**
Installation and maintenance of drinking fountains or equipment	6	2	5	1	4	8.87%	1	1	6	5	3	10.39%	6	-	2	1	4	6.50%
Leaks and defects in faucets	11	19	21	18	9	38.42%	7	9	2	7	1	16.88%	21	17	18	20	16	46.00%
Leaks and defects in flush valves	16	1	5	3	10	17.24%	9	7	7	24	9	36.36%	7	10	3	2	6	14.00%
Leaks and failures in storage tanks	2	7	4	2	-	7.39%	-	-	1	2	-	1.95%	3	2	2	6	3	8.00%
Lack of water or inadequate pressure	2	1	-	2	-	2.47%	-	5	1	4	5	9.74%	2	3	-	-	3	4.00%
Leaks in pipes or faucet supply line	12	5	10	8	6	20.20%	5	2	4	9	3	14.94%	5	4	16	9	3	18.50%
Leaks and defects in valves	7	3	-	1	-	5.42%	1	1	-	1	1	2.60%	3	1	-	2	-	3.00%
Defects in bidet faucet	-	-	-	-	-	0.00%	4	3	2	-	2	7.14%	-	-	-	-	-	0.00%
Total	56	38	45	35	29	203	27	28	23	52	24	154	47	37	41	40	35	200
Annual percentage for plumbing systems	53.33%	43.18%	47.87%	38.46%	39.19%	-	40.91%	46.67%	32.86%	47.27%	36.92%	-	41.96%	34.58%	30.15%	40.00%	34.65%	-

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Table 7: Maintenance records reported in Group 2 buildings for the sewage drainage building system.

Building	TPPHI						CENTRAL LIBRARY						FACULTY OF DENTISTRY					
Sewage drainage	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**
Installation and maintenance of drinking fountains or equipment	5	4	2	1	1	6.16%	1	4	6	3	1	7.77%	5	1	4	1	2	4.08%
Blockage or leaks and defects in siphons	20	18	18	20	20	45.50%	8	5	11	16	7	24.35%	10	25	20	10	8	22.96%
Blockage in toilet bowls	13	6	7	11	7	20.85%	17	9	16	21	14	39.90%	18	19	4	11	5	17.92%
Blockage in floor drains	1	1	3	1	5	5.21%	-	3	1	1	1	3.11%	7	10	11	15	9	16.35%
Returns of odor	1	1	-	2	-	1.90%	-	3	1	-	-	2.07%	5	3	8	5	-	6.60%
Washbasin or toilet bowl detachment	1	1	-	10	2	6.64%	1	3	1	1	11	8.81%	-	4	3	5	9	6.61%
Leaks in pipes and inspection shafts	4	2	6	2	2	7.58%	1	1	2	8	1	6.74%	12	4	26	9	11	19.50%
Blockage in urinals	1	1	2	6	3	6.16%	1	2	4	3	4	7.25%	2	2	1	3	11	5.97%
Total	46	34	38	53	40	211	29	30	42	53	39	193	59	68	77	59	55	318
Annual percentage for plumbing systems	43.81%	38.64%	40.43%	58.24%	54.05%	-	43.94%	50.00%	60.00%	48.18%	60.00%	-	52.68%	63.55%	56.62%	59.00%	54.46%	-

Table 8: Maintenance records reported in Group 2 buildings for the rainwater drainage building system.

Building	TPPHI						CENTRAL LIBRARY						FACULTY OF DENTISTRY					
Rainwater drainage	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**	**2015**	**2016**	**2017**	**2018**	**2019**	**%**
Leaks and clogging in gutters	-	2	1	-	1	10.53%	1	-	-	-	1	8.33%	-	-	3	-	1	10.53%
Occurrence of infiltrations	1	4	8	2	3	47.37%	9	1	5	4	1	83.33%	3	1	14	1	10	76.32%
Roof maintenance requests	2	10	2	1	1	42.11%	-	1	-	1	-	8.33%	3	1	1	-	-	13.16%
Total	3	16	11	3	5	38	10	2	5	5	2	24	6	2	18	1	11	38
Annual percentage for plumbing systems	2.86%	18.18%	11.70%	3.30%	6.76%	-	15.15%	3.33%	7.14%	4.55%	3.08%	-	5.36%	1.87%	13.24%	1.00%	10.89%	-

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Through the proposed methodology, it was estimated the cost that would be spent if all maintenance work orders recorded were executed. Table 9 presents the updated initial cost for the construction of the plumbing systems and the annual values referring to the maintenance cost of these systems per building. The maintenance costs found are quite significant, considering that they refer to the initial five years of use and operation of the plumbing systems (newly completed work).

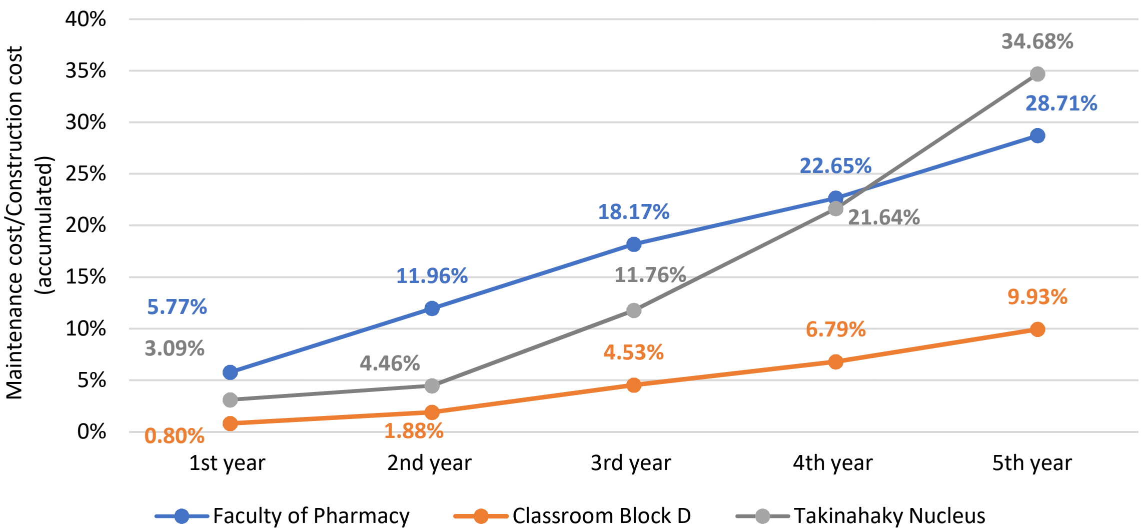
Table 9: Costs referring to the construction and maintenance stages of the Group 1 buildings.

Building	Building phases						
	Construction	Maintenance					
	Updated contract cost ($US) *	1st year ($US) *	2nd year ($US) *	3rd year ($US) *	4th year ($US) *	5th year ($US) *	TOTAL ($US) *
Faculty of Pharmacy	52,827.88	3,045.65	3,272.68	3,282.66	2,362.59	3,204.00	15,167.58
Classroom Block D	63,853.17	512.47	689.68	1,687.29	1,444.35	2,007.89	6,341.68
Takinahaky Nucleus	7,809,03	241.61	106.34	570.67	771.06	1,018.74	2,708.42

* Reference date: January 3, 2022.

Fig. 10 shows, in cumulative percentages, the relationship between the expenditure on plumbing systems maintenance and the initial cost of construction of these systems. Evaluating the percentages found for the first year of use of buildings, when maintenance interventions on the systems should be minimal and sporadic, high values were observed, especially for the Faculty of Pharmacy (5.77%) and for the Takinahaky Nucleus (3.09%). For all buildings evaluated, the accumulated percentage showed sustained growth, with emphasis on the Takinahaki Nucleus, which during the five years evaluated recorded a maintenance cost greater than one-third of all the amount spent on the construction of the plumbing systems (34.68%).

Figure 10: Relationship between the expenditure on maintenance and the initial construction cost of the plumbing systems in cumulative percentages.



The results verified in Fig. 10 point to accelerated depreciation of the buildings in Group 1 and may be related to inadequate maintenance procedure, similar to the analyzes observed by LATEEF *et al.* (2010) and deficiencies in the other previous phases of the project, as also observed by HASSANAIM *et al.*, (2019) and MORAIS and LORDSLEEM (2019).

3.1. Discussion and recommendations

Considering all the buildings covered, the buildings that registered the highest incidence of maintenance are from Group 1: Takinahaky Nucleus for the water supply and sewage drainage systems; and Faculty of Pharmacy, for the rainwater drainage system – both buildings started operation in 2014. This questions the quality of new constructions, which, throughout this study, presented lower performance levels than the plumbing systems of much older buildings. As reported by Hopkin *et al.* (2017) and Abdullah *et al.* (2021), it would be expected that newly completed buildings would have lower maintenance rates than older buildings. However, these buildings - built using low-quality and unreliable materials - further overload the maintenance system of universities, which no longer work properly. It is verified that the sector responsible for the institution's building maintenance mainly engages in corrective maintenance actions. It faces difficulties in stock management, lacks materials and equipment, and has an undersized and relatively unqualified team.

The results indicated similarity between the most frequent occurrences verified for the buildings of the two groups. However, the current demands for buildings in Group 2 (aged over 20 years) have their maintenance records related to chronic problems already existing in the building, intense or inadequate use, natural wear and tear, and deficiencies in the maintenance and conservation activities of these buildings (KHALID *et al.*, 2019; LATEEF *et al.*, 2010). The pathological manifestations reported for Group 1, referring to the first five years of use and operation of the buildings, as indicated by Hassanain *et al.* (2019) and Khalid *et al.* (2019), may be more related to failures in the design process, contracting and work execution, the quality of the materials used, or the solutions adopted in projects.

The study indicates the need for improvements in the details of plumbing designs, in order to bring the forecast of all equipment, including drinking fountains, to avoid further adaptations. Buildings characterized by high user occupancy and serving a broad university community should receive special treatment regarding the specification of more durable materials, resistant-to-use devices, and the development of maintenance plans that include these characteristics.

Considering the high incidence of defects and failures in roofing systems, projects for rainwater drainage systems must be correctly detailed, with elements to support traffic and equipment disposition that are sometimes supported directly on the tiles; thus, avoiding the transit of people directly over the roof, which damages the elements that compose it.

The projects and technical specifications for plumbing facilities must provide guidelines and instructions based on the solutions adopted for preparing maintenance plans for the buildings.

Finally, the significance of an efficient and active maintenance plan is highlighted, considering each building’s particularity, such as the existing sanitary equipment and appliances, levels of occupation of spaces, and the activities carried out. This level of operational planning that contemplates preventive and predictive actions, if executed in a planned way in the most opportune periods, allows for inventory planning and financial management of maintenance activities, essential factors in the implementation of a building maintenance plan.

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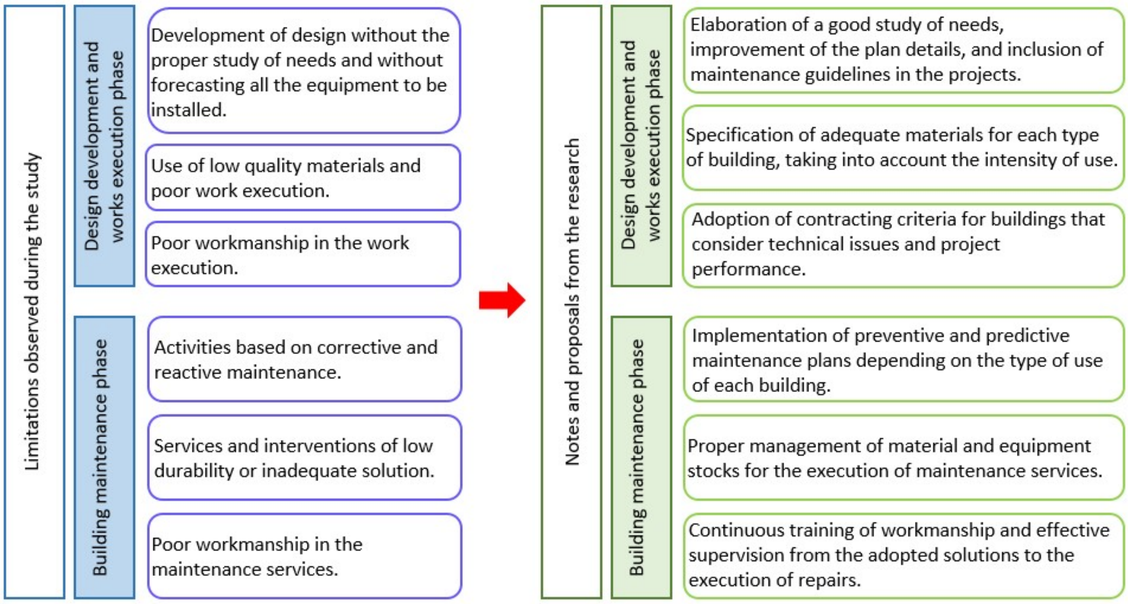
As a summary of the discussion and to briefly present the results, Fig. 11 shows the main limitations found in the case studies and the main proposals for improvements.

Figure 11: Summary of the main limitations and guidelines found throughout the study.



4. Conclusions

The analysis of the institution's building maintenance work order made it possible to diagnose the origin of the demands of the evaluated maintenance system. It was found that most work orders are related to the building systems and from these, the representativeness of the plumbing systems drew attention, which had a percentage of 36.48% of the demands.

The analysis of buildings by age range observed a high share of newly completed buildings requiring maintenance services, consequently increasing service demands as new buildings were included in the university's physical structure. By analyzing the two groups of buildings, the high maintenance rates in the buildings in Group 1 (age range up to 20 years) stand out, which in most cases, presented higher values than buildings in Group 2 (buildings older than 20 years). This fact points to the low quality of new buildings, indicates a current lack of adoption of sustainable criteria in public buildings and the need for improvements in the processes of designing and execution, steps that directly affect the maintenance of these buildings.

It was observed that the forms of contracting in the Brazilian legislation influence the building of public facilities. The dynamics of budget availability associated with deadlines for the execution of financial commitments, resource limits and political issues are the most influential constraints on the projects, despite technical studies of users' needs, minimum requirements for building performance and sustainable issues. The proposals selection in bidding procedures is based on the lowest price criterion, without considering the quality of the product. In this way, the execution process of the works is primarily guided by the parameter of economy, disregarding the quality and durability of the installations in many cases. During the use and operation phase, numerous maintenance demands arise from deficiencies in the design and execution stage of the building. These demands overload the existing maintenance system, which is also limited to budget issues and lack of planning, affecting the quality of maintenance activities for both new and old buildings.

This research emphasizes the significance of understanding a building maintenance system and the performance of the buildings that are part of it. This was necessary for developing maintenance plan guidelines presented in this study. These data are also valid for improvements in project design, work execution, inspection, and approval of similar buildings, to reflect on sustainable conditions for maintaining new and existing buildings.

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