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APPLICATION OF DRONES IN CIVIL CONSTRUCTION FOR PHYSICAL MONITORING OF WORKS

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ABSTRACT
The work addresses the use of drones in civil construction, focusing on the physical monitoring of works and the detection of structural pathologies. The study presents the advantages of drones, such as cost reduction, greater efficiency, and safety in inspections of hard-to-reach areas. With the use of advanced sensors and high-resolution cameras, drones offer a faster and more accurate alternative to traditional monitoring and inspection techniques. The research includes a comparative analysis between the use of drones and the conventional method with scaffolding, highlighting the economic and operational benefits, with a case study referring to a building in the West Zone of Rio de Janeiro to exemplify the practical application of drones in the field.

Keywords: Civil Construction. Pathology. Construction Control. Drone.

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INTRODUCTION

Civil engineering plays an essential role in urban development and improving the quality of life, but it still faces significant challenges in adopting advanced technologies. Although progress has been made in replacing manual labor with machinery in some activities, many processes still rely on manual methods, which limits productivity and impacts essential pillars of any project: time, cost, quality, and safety (Leite et al., 2021; Gonçalves, 2020). These challenges reinforce the need for solutions that optimize resources and increase operational efficiency. The use of drones has gained popularity recently, due to their versatility, they have been used in different areas. The term drone is an umbrella term to describe an unmanned aircraft, which can be autonomous or remotely piloted by humans.

The search for innovations that integrate and enhance these pillars simultaneously has led to the growing use of drones in civil construction. Although invented more than a century ago, drones initially had applications restricted to the military context. It was only in the 1960s, with the introduction to the civilian market, that its potential began to be explored in areas such as agriculture, logistics, and, more recently, civil engineering (Campos et al., 2019). Currently, drones are widely recognized for their ability to improve processes and reduce costs, especially in critical tasks such as topographic surveying, construction monitoring, and building inspections (Zitzmann, 2022; Chiminelli et al., 2023).

In civil construction, drones have stood out as strategic tools for façade inspections and pathology analysis. These technologies make it possible to reach hard-to-reach places, reduce task execution time, and improve worker safety by eliminating the need for scaffolding and height equipment (Melo, 2016; CPETecnology, 2023). In addition, the accuracy of data captured by drones has surpassed traditional methods, such as total stations and manual surveys, with gains in productivity and quality (Campos et al., 2019; Works10, 2024).

However, despite their benefits, the use of drones is still not widespread in the industry, often due to a lack of technical knowledge and the need for compliance with specific regulations, such as ANZAC's RBAC-E No. 94 (2017). This work seeks to explore how drones can transform the management and execution of works in civil construction, addressing their practical applications, economic and operational benefits, with a focus on monitoring works and identifying pathologies. Innovations are more necessary because the civil construction industry is characterized by having a workforce with a low level of

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education, archaic production processes, high turnover, and high risks to the health of the worker (Awwad; El Souki; Jabbour, 2016; Costa, 2010).

Authors such as Hee-Wook, Hyung-Jin, and Sung-Keun (2023) highlight that the use of drones in civil engineering creates an era of efficiency, precision, and safety throughout the various phases of construction projects. An interesting application in the field of civil engineering is the use of drones to monitor works, this allows a better analysis of the necessary conditions for the infrastructure. As can be seen in Figure 01, they can be used to inspect constructions in progress, without the need for the presence of people on site, which ends up being important to ensure the safety of workers and makes it possible to save work time. This makes them indispensable for construction projects, where safety and accuracy are paramount. From the analysis of the images captured by the drone, it is possible to detect possible structural failures and other adverse effects such as drills in structures.

Figure 01: Use of Drones in Civil Construction

Source: SIENGE (2022)

THEORETICAL FRAMEWORK

The low productivity of civil construction compared to other economic sectors is a recurring problem, often attributed to resistance to the adoption of new technologies (Nascimento; Denadai, 2021). With the introduction of drones, this situation begins to change, especially about the monitoring of works and the inspection of structural pathologies. Drones equipped with GNSS and RTK sensors, for example, allow for accurate mapping and diagnosis, with the generation of high-resolution three-dimensional models, reducing the time and cost of inspections (Santos et al., 2022).

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CIVIL CONSTRUCTION

In the field of civil construction, technological innovation has been a watershed in overcoming traditional challenges. Technologies such as drones and 3D modeling have accelerated processes previously performed manually, often susceptible to errors and time-consuming (Morgenthau and Hallermann, 2014). This is essential for the planning of works, contributing to minimizing schedule deviations and increasing safety on site.

Civil construction is historically recognized as a strategic sector for economic and social development. However, it faces critical challenges related to productivity, efficiency, and technological modernization. Studies such as those by Mattos (2018) indicate that, while industries such as automotive and electronics have evolved significantly in terms of automation, civil construction still largely relies on conventional methods. This dependence negatively affects the sector's ability to meet growing demands for infrastructure and housing.

Another relevant point is the impact of technologies on the tripod of time, cost and quality. This scenario is especially important in a sector that historically has low productivity rates compared to other branches of industry.

STRUCTURAL PATHOLOGIES: DIAGNOSIS AND SOLUTIONS

Structural pathologies, when not detected early, can compromise the safety and durability of buildings. According to Medeiros et al. (2018), the main pathologies found in buildings are cracks, infiltrations and detachments, which often occur due to execution failures or the use of inappropriate materials. Early detection of these anomalies is crucial.

According to Albuquerque (2015), the main causes of pathologies found in building works are the deficiency in the design of the project, the low quality/defect of the materials used, the failures in execution and the use of structures (maintenance). The development of the construction process can be categorized into three distinct phases: the project design phase, which covers planning, calculations, drawings and selection of the necessary materials, followed by the execution phase, in which the tasks are carried out according to the schedule established for the work, and finally, the use phase, which requires the coherent and adequate use of space as originally designed. (Albuquerque E., 2015).

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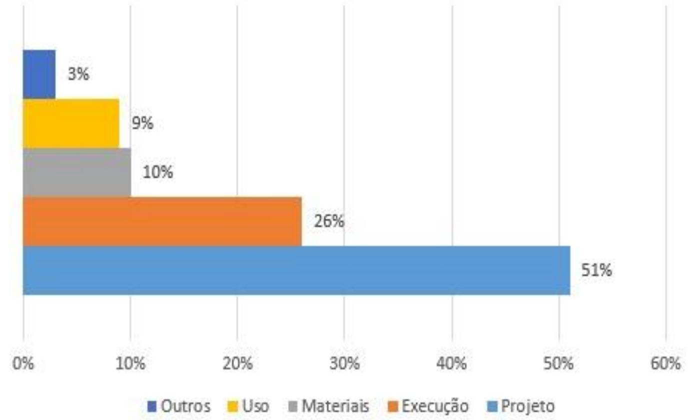
Graph 1: Causes of anomalies in buildings



Source: Adapted from COUTO, J., 2007, p.5.

Structural pathology is a constant concern in civil engineering, as it is associated with the durability and safety of buildings. Among the most common manifestations are cracks, infiltrations, and detachments, which can compromise the functionality and integrity of structures (Frazão et al., 2019), and can also use thermography to detect infiltrations, thermal insulation failures, and other hidden pathologies. Early diagnosis of these pathologies is essential, but conventional methods, such as visual inspections, are limited by difficulties in accessing elevated or hard-to-reach locations.

Structural pathologies, or manifestations of failures in buildings, are a recurring problem in civil engineering. These can arise due to a variety of factors, including design flaws, improper execution, or the use of low-quality materials (Melo et al., 2017). The consequences of these pathologies can range from simple discomfort for users, to structural collapse, with significant economic and social implications.

Figure 02: Pathology

Termos	Definição	Patologia das construções	Patologia médica
Manifestações patológicas	São os problemas visíveis ou observáveis, indicativos de falhas do comportamento normal	Fissuras, trincas, machamentos, deformações, mofo	Dor de cabeça, enjoo, tontura
Fenômeno	É a raiz do problema, na qual se deve focar para a solução	Corrosão, eflorescência, recalque	Câncer, depressão
Inspeção	É o *check-up*, quando o patólogo ou médico avalia o seu paciente, aprovando a condição ou solicitando novos exames ou ensaios	Avaliar a estrutura regularmente ou quando houver um fato extraordinário de interesse	Avaliar a pessoa para saber a condição atual de saúde
Anamnese	É o estudo dos antecedentes; nessa etapa, deve-se escutar dos usuários e pacientes o que estão sentindo	Conversa com síndico e moradores antigos, análise de projeto, verificação do estado dos prédios vizinhos	Análise de histórico do paciente e dos familiares, verificação de exames anteriores
Ensaios não destrutivos	São ensaios/exames que não danificam o paciente	Esclerometria, pacometria, ultrassom	Medição de pressão e febre, ultrassom
Ensaios semidestrutivos	São ensaios/exames que causam pequeno dano ao paciente	Extração de corpos de prova, *pull-out*	Biópsia, exame de sangue
Diagnóstico	É a explicitação e o esclarecimento das origens, mecanismo, sintomas e agentes causadores do fenômeno ou problema patológico	Corrosão, eflorescência, recalque	Câncer, depressão
Profilaxia	São as medidas preventivas para que o problema não ocorra	Manter cobrimento correto das armaduras, fazer uso adequado da construção, manter a pintura da fachada íntegra	Escovar os dentes cinco vezes ao dia, manter uma alimentação saudável, praticar exercícios
Prognóstico	É a análise da progressão da enfermidade, se nada for feito para erradicá-la	Aumento da fissuração, deformação excessiva, colapso	Perda da visão, expansão do câncer para outros órgãos, morte
Terapia	São as medidas para neutralizar o fenômeno devolvendo o desempenho ou a qualidade de vida ao paciente. É o estudo das intervenções corretivas viáveis	Refazer elemento corroído com proteção da armadura, retirar sobrecarga, reforçar estrutura	Quimioterapia, remédios, praticar esportes

Source: Adapted by the author from Pathology and structures.

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Through a study carried out by Batista, Augusto, Evangelista (2023), which addresses pathologies, possible causes, degree of aggressiveness and tendency to worsen over time, presented in a particular development, located in Barra da Tijuca. Such anomalies can develop depending on the way the work was carried out or actions resulting from time without any maintenance to prevent the appearance. The following cases mentioned as cracks and cracks can be exposed, which although they can be confused, they have different sizes. Cracking occurs when this opening increases (between 1 and 3 mm) to the point of dividing the structure, such as the walls, into two distinct parts. Cracks, on the other hand, are characterized by openings (above 3 mm) through which wind and rainwater can pass, for example, and can be seen in the following images:

Figure 03: Example of crack

Source: Image by the author

Figure 04: Example of cracks

Source: Image by the author

Also according to Batista, Augusto, Evangelista (2023), the image found in another region illustrates a constructive and exogenous anomaly. The pathology presents itself as a crack, which was created, because probably the glued roughcast used at the bottom of the beam has expired its useful life, or even been made improperly, causing the plaster to lose adhesion and detach from the surface and also the lack of waterproofing, so it is advisable to countersink the region to clarify if there is no other factor, Remove existing plaster, sublayer of glue plaster and redo procedure.

CONTROL OF WORKS

Construction control is another critical point in civil construction, which involves the integrated management of deadlines, costs and quality. The lack of adequate tools for monitoring contributes to delays, budget increases, and low efficiency. Despite the importance of construction control, it is often hampered by communication failures and lack of accurate tools for monitoring. According to Mattos (2018), these limitations are one of the main causes of delays and budget overruns in large-scale projects.

Civil construction is a sector historically associated with high levels of waste and inefficiency. Data show that delays, budget overruns, and quality failures are recurrent in many projects. These problems usually result from inadequate planning or flawed control during the execution of the work. According to Alencar and Mello (2020, p. 35), the effective control of works "depends on an integration between technological tools, well-defined processes, and training of the professionals involved".

Deadline monitoring also involves critical analysis of the schedule. To ensure that activities are being completed on time, managers should carry out periodic reviews and, when necessary, readjust resources or teams. According to studies by Martins (2023, p.67), the "constant review of the schedule, associated with the analysis of the performance of resources, is crucial to avoid bottlenecks and ensure the fluidity of execution".

INTEGRATION OF DRONES IN CIVIL ENGINEERING

According to the Department of Airspace Control - DECEA (2023), the term "drone" is used informally and popularly to refer to equipment that can be operated from a distance. Drone, which in Portuguese translates as "drone", originated from the type of noise that these devices usually emit during flight, similar to the sound produced by a drone.

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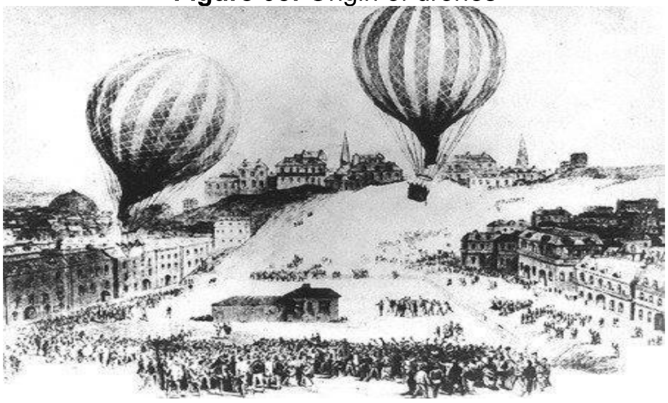
Figure 05: Origin of drones



Source: Smart Energy (2016)

Drones, also known as Unmanned Aerial Vehicles (UAVs), initially emerged for military purposes, but over the past few decades, they have expanded to various sectors, such as agriculture, construction, and entertainment. The popularization of this technology was driven by the development of GPS navigation systems and the miniaturization of electronic components, which allowed the manufacture of smaller and more affordable drones for civilian use (Santos; Lima, 2018).

In the military context, the use of drones dates back to World War I, when they were used for reconnaissance and espionage missions. However, it was only from the 1990s onwards that drones began to play more active roles, with the development of models equipped with high-resolution weapons and cameras (Almeida et al., 2019). This technological advancement was fundamental to expand the possibilities of application of drones in non-military sectors.

Finally, the emergence of drones has revolutionized the way various industries perform previously complex or unfeasible tasks. Its impact continues to grow as new applications are developed, especially with the use of artificial intelligence and advanced sensors that allow for real-time monitoring and autonomous execution of various activities (Rocha, 2021).

Nowadays, drones have many functions, from more everyday activities such as climate change monitoring, as well as post-disaster rescue activities, photographs, filming, product delivery, inspections, among others (Imperial War Museums, Undated). On December 19, 1986, the Brazilian Aeronautical Code (CBA) provides in article 106 of Law No. 7,565 that the definition of aircraft is:

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An aircraft is considered to be any maneuverable device in flight, which can sustain itself and circulate in the airspace, through aerodynamic reactions, capable of transporting people or things (BRASIL, 1986).

It is necessary to emphasize that ANAC, together with DECEA and ANATEL, regulates the use of drones in Brazil. Resolution 451/2017 defines classes of drones and operational restrictions, such as the prohibition of flights above 400 feet without specific licenses (Anac, 2017).

Figure 06: Table "Summary of Anac's Regulation

Resumo da Regulamentação da ANAC				
	RPA Classe 1	RPA Classe 2	RPA Classe 3	Aeromodelos
Registro da aeronave?	Sim	Sim	BVLOS: Sim VLOS: Sim [1]	Sim [1]
Aprovação ou autorização do projeto?	Sim	Sim [2]	Apenas BVLOS ou acima de 400 pés [2]	Não
Limite de idade para operação?	Sim	Sim	Sim	Não
Certificado médico?	Sim	Sim	Não	Não
Licença e habilitação?	Sim	Sim	Apenas para operações acima de 400 pés	Apenas para operações acima de 400 pés
Local de operação	A distância da aeronave não tripulada NÃO poderá ser inferior a 30 metros horizontais de pessoas não envolvidas e não anuentes com a operação. O limite de 30 metros não precisa ser observado caso haja uma barreira mecânica suficientemente forte para isolar e proteger as pessoas não envolvidas e não anuentes. Esse limite não é aplicável para operações por órgão de segurança pública, de polícia, de fiscalização tributária e aduaneira, de combate a vetores de transmissão de doenças, de defesa civil e/ou do corpo de bombeiros, ou operador a serviço de um destes.			

Source: Anac (2017)

According to the publication of IBAPE/SP - Building Inspection: The Health of Buildings (2015), the majority (66%) of accidents in buildings over 30 years old are related to deficiencies in maintenance, premature loss of performance or significant deterioration, while only 34% have causes linked to construction defects or internal anomalies.

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Graph 2: Building Inspection: The Health of Buildings (2015)

Source: IBAPE-SP (2015)

METHODOLOGY

CASE STUDY

Yin (2016) states that through the case study it is possible to understand complex social phenomena, since it allows us a global view of the main characteristics of the event, which is a pertinent technique when the main research questions deal with contemporary facts. Corroborating the case study technique, Rodrigues (2005) exposes that the case study, as a research strategy, is the best adaptation to collect and analyze the desired empirical evidence. According to the typologies applied to the work, as for its approach, the research can be considered predominantly qualitative, since it is characterized by the non-use of statistical instruments (Pereira et al., 2017). The case studied in this work referred to a verification in the form of videos and photos of the façade of an 18-story building under construction with three towers, located in the west zone of Rio de Janeiro.

In the case study, a step-by-step process will be made to carry out the service with the use of a drone, from the choice of the appropriate equipment and its acquisition, planning the operation and execution taking into account the moments of pre-realization, day of flight and post-operation. During the study, a brief analysis of the images of the types of pathologies found on the façade will also be made. With the compilation of information, a brief analysis of the method will be made and comparisons will be made with the traditional method currently known. Drones are equipment that can be considered expensive to acquire, however, the construction company in question verified the model and brand that would best suit to carry out operations to monitor the work in general, and the maximum amount of activity carried out can be extracted.

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The equipment chosen was the DJI MINI 4 PRO, due to the identity of the service to be performed, which required equipment that could fly with stability, perform landing and takeoff without needing long areas and being able to move vertically with ease.

Figure 07: DJI MINI 4 PRO Drone

Source: DJI website

According to the drone's official website: the total value of the drone, 2 sets of batteries and control is approximately R$12,299.00. According to Anac regulations, the RPA was classified as class 3 due to the flight weight. Through this classification, the necessary regulations for the type of operation were known. The pilot's license and qualification were not necessary because the flight did not exceed 400 feet in altitude.

Figure 08: Start of operation

Source: Image by the author

The reduction in the cost of the service is not only due to the execution time. One factor that makes the service cheaper is labor. For cases of work at height, the professional

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needs to be trained. The professional often has NR35, NR18 and IRATA certificates. Based on research carried out in the market, the cost of such a professional becomes very high, and can vary between R$400 and R$600 reais per day. To fly a drone, there is no specific training or certificate that is required in Brazil. In the study in question, the device was handled by an intern. In this way, the cost of labor for the service becomes lower than that of the traditional method, and there is sometimes no need to hire a specialized pilot for the service, since the company owns the equipment and instructions were given to perform the service properly.

Initially, a *checklist* was created before starting the takeoff, which is based on the preparation of the equipment, to which the drone is removed from the box, the items present are checked, then the remote control was turned on, the battery charge level was checked, connected to the cell phone and soon after, the control and the drone were turned on to make sure everything was working. The battery change was not necessary, since, with the time of only one battery, the service was already completed. The flight began in the morning and lasted 28 minutes. During the service, high-resolution photographs were captured and videos were obtained to display the pathology.

Fgura 09: Capturing the images

Source: Image by the author

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Figures 10 and 11: Pathologies found

Source: Images by the author

Figure 12: Pathology recorded

Source: Image by the author

Figure 13: Pathology verified

Source: Image by the author

Upon finishing capturing the images, the drone was landed in a safe place and it was checked if the object had any type of damage, where it was identified that it was in excellent condition. At the end of the operation, the images were passed on to the engineers responsible for the construction to verify the severity and options to solve the existing pathology. It was verified that it was necessary to countersink the part that had the

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drills and then the structure was gouted, the service took about 4 months to be completed, as the pathology was presented in several areas of the structure.

COMPARISON OF METHODS

When compared to traditional inspection methods, such as the use of scaffolding or lifting platforms, drones offer significant advantages. According to Gheisari et al. (2020), drone inspection reduces operating costs by up to 40%, as it eliminates the need to set up temporary structures for access to elevated locations. In terms of efficiency, drones allow you to carry out inspections of large areas in a fraction of the time required by conventional methods.

Zhou et al. (2021) showed that drones can perform façade inspections in up to 30 minutes, while the same service performed with scaffolding can take days or weeks, depending on the extent of the building. On the other hand, the use of drones for inspections is limited if there is a need to check between buildings very close to the structure in question, which does not occur by the traditional method. A comparison was made between the use of the drone to inspect the façade of the building and the assembly of a scaffold to verify the possible pathology, addressed in the case study, through surveys and quotation via telephone.

Figure 14: Comparison table between drones and scaffolding

COMPARAÇÃO		
EQUIPAMENTO	**DRONES**	**ANDAIMES**
CUSTO	Custeado pela construtora	R$ 450 (Diária do equipamento)+ R$ 765 (Montagem e desmontagem) + R$ 1.400 (Frete)
EXECUÇÃO DO SERVIÇO	28 Minutos	1 HORA (Em média com o equipamento montado)
TEMPO DE MONTAGEM	3 Minutos	DE 1 A 3 DIAS (Podendo variar por conta da quantidade e posicionamento)
SEGURANÇA	Reduz o risco de acidentes, eliminando o trabalho em altura	O operário tem que possuir treinamentos
METODOLOGIA	Sobrevoar e realizar registros	Operar o equipamento e realizar reparos
MÃO DE OBRA	1 ESTAGIÁRIA	2 OPERADORES (Mínimo)
VALOR DE MÃO DE OBRA (DIÁRIA)	R$ 55,44 (Aproximadamente)	R$ 800 (R$ 400,00 x 2 operarios)

Source: Worksheet prepared by the author based on research

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CONCLUSION

The incorporation of drones in civil construction represents an essential innovation to overcome the challenges faced by this sector, such as low productivity, high operating costs, and risks to worker safety. This work demonstrated that the use of unmanned aerial vehicles provides clear benefits in critical areas, such as the diagnosis of structural pathologies, the control of works and the planning of projects.

In the context of structural pathologies, the use of drones for façade and roof inspection offers a more efficient, safer, and cost-effective approach when compared to traditional methods, not only reduces the time required for inspections, but also eliminates the need for scaffolding or lifting platforms, minimizing the risks associated with working at height.

In construction control, this technology has transformed project management by providing real-time data on the progress of activities. The capture of aerial images allows you to identify irregularities and deviations from the schedule efficiently, helping managers in decision-making.

In addition, the ability of UAVs to perform volumetric measurements with high accuracy optimizes steps such as earthmoving and material movement, reducing waste and maximizing available resources.

This transformation also results in improved safety on construction sites, highlighting the role of drones in preventing accidents. Technological advances and the growing interest in the use of drones indicate a promising path for their large-scale application in civil construction. It is concluded that it not only offers practical solutions to historical problems in the sector, but also sets new standards for efficiency and safety.

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