Research Article

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New trends in visual inspection of buildings and structures: Study for the use of drones

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Abstract: Visual inspection is a very simple, non-destructive technique and usual in diagnosing buildings and structures' conditions. It also plays an important role in the rapid assessment of constructive problems as well as in the definition of an appropriate way for eventual remedial interventions. However, the use of this methodology often meets difficulties, especially when places to be inspected are difficult to access; it involves security risks for inspectors or even when a reactive inspection of urgent nature becomes unfeasible due to the high costs and the necessary means involved. In this context, the introduction of new technologies, such as drones, can bring substantial benefits. Currently, great focus has been put on this type of device as an emerging technology in the construction industry. This article treats about a reflexion on the adaptability and versatility of using drones, within a framework for monitoring the condition of buildings' envelope, just as for other kinds of structures (e.g. bridges, viaducts, dams, chimneys, etc.). The interest lies, for now, in devices with a multirotor configuration, integrating high-definition cameras for both photography and video. In order to verify these assumptions, several field tests are being performed, of which some examples are presented.

Keywords: drones, inspection, buildings, structures, pathologies

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Abbreviations

BIM	building information model
BMM	building maintenance management
CE	civil engineering
CI	construction industry
CRS	characterisation of reference state
HD	high definition
IES	inspection event sheet
LOS	line of sight
NARA	national airspace regulatory authorities
NDT	non-destructive testing
RPAS	remotely piloted aircraft system
SIAPME	information system for automatisation of procedures in the building maintenance management (initials in Portuguese)
SMP	strategic maintenance plan
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
VANT	veículo aéreo não tripulado

1 Introduction

In 2018, licensed rehabilitation works in Portugal grew 11.7% compared to the previous year (−0.1% in 2017), corresponding to 5,187 buildings [1]. With regard to other types of structures, in the same year, the national state body “Infrastructures of Portugal” was in charge of more than 7,200 auxiliary constructions, i.e. bridges, viaducts, tunnels and hydraulic passages, that is, structures with more than 2 m of span, belonging to the road and rail networks [2]. According to an assessment carried out by the same entity, although around 87% of railway structures are in satisfactory or in good condition [3], a need is still felt to find safer and more efficient methods to perform visual inspection with quality and safety, since this is one of the essential techniques in rehabilitation and conservation work.

It is in this sense that drones can make a difference in the technical inspection of buildings. Several researches

have been accomplished to demonstrate the applicability and usefulness of drones in the construction sector [4–6].

A research [4] presented the relationship between user needs, existing solutions and what drones can bring back regarding the different phases of the construction life cycle (site survey, construction progress and monitoring, material tracking and facilities management). A conclusion of this study indicates that the use of drones has great advantages and can even be a fundamental tool for rehabilitation scenarios, when interconnected with “building information model” (BIM), thus providing real-time data on the conservation status of envelopes of buildings and other constructions.

Thus, drones have also gained some prominence in construction because their use can be more economically viable than other traditional visual inspection methods. Although the volume of literature which directly addresses the economic advantages of using drones for visual inspection is still scarce, it is nevertheless possible to assess, from some works performed [6], the impact that these may have on the overall costs of inspection work, especially by dispensing with any type of auxiliary means, as scaffolding, and by not producing significant disturbance to constructions during inspection. Being a recent technology in the civil engineering (CE) domain, there has been a continuous effort to find methodologies for the correct use of drones in the inspection of buildings and in civil infrastructure systems. As a recent technology in CE domain, there has been a continuous effort to find methodologies for the correct use of drones in building inspection and civil infrastructure systems. Some studies [7–11] go in that direction and their proposals, in general, try to take into account all the factors that can influence the inspection, such as type of drone, weather conditions, the kind of construction under analysis, etc. For instance, in [8] a five-step methodology is suggested: the first is to collect all the information from the construction to be inspected; in the second step, a risk assessment is foreseen, analysing the surrounding areas, searching for potential hazards for inspection, such as trees and traffic of people or vehicles; the third stage consists of a “preflight setup,” checking the status of the drone’s software and hardware; in the fourth stage, the inspection is carried out; and finally, in the fifth stage, the detected anomalies are identified and studied. Also, in a study for inspection of constructions using thermography [7], a protocol with four phases is proposed. In this case, the first phase consists of a general outline of conditions for the use of drone, such as the characteristics of the building to be inspected, the legislation in force, meteorological data and the choice of a

safe zone that enables the pilot to have good visibility when manoeuvring the device; in the second stage, a security perimeter should also be provided (as considered in ref. [8]); the third stage refers to the specifications of camera to be used, the angles and distances to the object under study and the drone’s manoeuvring speed; and in the final stage, a flight pattern is projected, followed by its achievement and data collection. In both these cases of study, certain setbacks were found, as related to the weather conditions, which can make it difficult to fly and move the drone to hidden or remote areas of the structures. So the perception is that while it involves difficulties to be overcome, drones have nevertheless been making a stand in the construction sector, namely when used in the visual inspection of large-scale structures and contributing increasingly to more detailed, economic and rigorous inspection reports while ensuring good safety and convenience levels, both for technicians carrying out on-site evaluations and for users of constructions under analysis.

2 Aims of the article

The purpose of this study is essentially to reflect on the adaptability and versatility of using drones in the context of condition monitoring of building envelopes and other civil infrastructure, such as bridges, viaducts, dams, chimneys, etc. In order to qualitatively assess the evidence of advantages of using drones over conventional means, authors have been developing in-depth studies on this subject and conducting several field trials. In an initial approach to the problem, tests have only been focused on building facade coatings or on vertical faces of certain structures.

3 Study methodology framework

3.1 Analysis of the underlying theoretical principles

An essential phase of research is the ongoing review of literature which allowed a detailed and updated perspective on several drone technology issues, its applications in CE (in particular with a focus on monitoring the structures and others within the construction industry [CI] as well as in the scope of inspections, at the level of both

building envelope and structures in general). For the purposes of this study, relevant literature was essentially gathered via search engines and/or databases such as Google, Google Scholar, Researchgate, Scindirect, Scopus, B-On, Emerald Insight, etc.

Treatment of collected information generically consisted of a seriation of each publication, according to the type of subthemes that interest our research. As it is not at all possible to present a more complete and incisive description about it in this text, we limit ourselves to highlighting certain aspects that seem to deserve greater attention for a better framing of the case studies performed.

Nevertheless, Table 1 sets out the literature review in a more quantitative approach, thus matching the number of references for each keyword (or the combination of keywords) as well as by identifying whether (i) these are the aspects of main focus (or even related) and (ii) at least one direct or indirect observation has been found (or an in-built relationship) for every single one.

3.2 Case studies

Within the scope of this article, only two case studies are presented. The first example relates to a facade of a residential building (“Case A” – also subject to prior analysis [12]) and the second is a chimney (“Case B”). Since both cases have a common peculiarity, that is, constructions with significant size in height, it was thus considered interesting to conduct a study with the summary characteristics comprised in this article.

Table 2 summarises some aspects for each situation.

3.3 Equipment used

Field tests were performed using drones equipped with high-definition (HD) camera. In “Case A,” the inspection analysis presented here refers only to one of its facades. A DJI Phantom 4-type drone was used for this situation [20]. In turn, for the inspection of chimney, a Parrot Bebop 2-type drone [21] was used.

3.4 Preparation of field work and flight operations

In particular, for “Case B,” pretesting procedures on-site were organised in more detail by topics, as briefly listed in Table 3 (based on previous research [13,14]).

It should be noted that the preparation of the field work and flight pattern are important aspects to be taken into account. The planning of a flight with drones requires attention to several factors such as the distance to the object to be inspected, the altitude and speed of the device. For instance, based on various sources, a study [15] has provided an idea of how the recommended distances can vary, although the ideal distance depends on each case. Thus, in “Case A,” a flight path with an average distance of 16 m from facade was pre-established (value used by operator’s option to safeguard the safety of the device). In “Case B,” this distance has already considerably been reduced, averaging 2 m (with occasional fluctuations) – allowing images’ extraction with a coverage of approximately 3.15×1.75 square meters. During tests (following the pre-established guidelines), the drone’s movement alternated in vertical ascents and

Table 1: Presentation of literature review using a quantitative approach

Keywords (or combination of keywords)	No. of matches for each one	References																		
		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]
Drones	15				X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Inspection	14	*	*	*	X	*	X	X	X	X	X	X	X	X	X	X	X	X	*	X
Buildings	12	X			X	*	X	X		*	X	X	X	X	X	X	X	*	*	X
Structures	10	X	X	X	*	*	X	X	X	X	*	*	*	X	X	*	*	*	*	X
Pathologies	11		*				*	X	X	X	X	X	X	X	X	X	X	*		X
Building inspection	11				X	*	X	X		*	X	X	X	X	X	X	X	*		X
Structural inspection	7		*	*	*	*	X	X	X	X	*	*	*	X	X	*	*	*	*	X

X – Each keyword (or combination of keywords) is one of the aspects of the main focus (or even related).

*At least one direct or indirect observation (or an inbuilt relationship) for every single keyword (or a combination of keywords) has been found.

Table 2: Description of case studies

		“Case A”	“Case B”
Description	Type of construction	Façade of a tall residential building, with 18 floors and over 54 m high. Currently it is empty	Clay brick chimney, 30 m high, circular shaft section and variable thickness disguised from base to top. It is deactivated, with aesthetic functions only. It has an outer surface coating of the ceramic type
	Age (years)	40	50
	Location	40°16′17.9″N 7°30′30.1″W Covilhã, Portugal	40°16′37.3″N 7°30′34.3″W
Main goals to be achieved		Quick assessment of general condition of the most inaccessible areas of facade, avoiding installation of auxiliary means	Quick assessment of general condition of the highest areas of outer surfaces without the installation of auxiliary means Highlight the representation of a predefined flight path

descents, associated with horizontal movements at its end, thus sweeping the entire extent of surfaces under analysis (further ahead, in figure inserted in Table 4, the flight pattern followed in “Case B” is illustrated). Flight operations were performed in “line of sight” (LOS), over a maximum duration of 20 min.

3.5 Data treatment and analysis

The results of drone inspections are subsequently treated in “back office,” in accordance with the objectives to be achieved. Computers with image, video and text processing software, spreadsheets, etc. are used.

Data collection and analysis are mainly based on a detailed evaluation of video recordings. Each video file is played back in slow motion (and repeated as often as necessary) so that each point in the flight path along the facade can be thoroughly checked for symptoms of anomalies, pathologies or damage. This can be done according to a predefined observation checklist (e.g. with forms of degradation display and severity of anomalies detected). Then for each type of occurrence verified, an image (or a set of photos) is selected and saved to be later organised with the others. All cases are individually treated, based on the inspector’s implicit knowledge and experience and eventually resorting to bibliography of speciality or even making possible comparisons with similar situations. In theory, in case of in-service constructions with a few years of age, the performance of inspection actions can fit into a context of repair, rehabilitation or maintenance management. For each hypothesis, it may be useful to use methodologies developed to study and/or classify the condition, thus allowing a structured presentation of results. In this article, the diagnosis is presented in an

abbreviated form in Table 5 (for the two exploratory cases studied), using a particular domain of a methodology developed for building maintenance management (BMM) [16], in particular focusing on the completion of some fields of an “inspection event sheet” (IES) model. This methodology was selected for purely illustrative purposes.

Usually, a detailed report is also produced and subsequently sent for consideration of asset owners’ entities. It contains proposals for corrective action to remedy the identified anomalies/pathologies.

4 Aspects of drone technology and its potential

In this text, the word “drone” is generically used, as it is a better known term and may even be better understood than other terminologies which regularly appear in literature and in normative or regulatory documents, such as “Unmanned Aerial Vehicle” (UAV), “Unmanned Aircraft System” (UAS), “Remotely Piloted Aircraft System” (RPAS) and “Veículo Aéreo Não Tripulado” (VANT), among others. In literature, several analyses can be found which allow a general and current perception about drone applications in different areas and contexts. Important publications [17,18] deal with configurations, system classification and other technological aspects of drones in a very detailed way. These are characterised by the differentiation of categories (from micro to large combat devices), their weight, operating altitude, radius of mission, autonomy, typical use, etc.

In the context of inspection of buildings and structures in general, it is accepted that the variety of drones to

Table 3: Summary of preflight and drone flight procedures (“Case B”)

Topics				
Fieldwork preparation	1 – Asset owners’ entities – requests for inspections/authorisations 5 – Airspace use – NARA’s authorisations granted (if applicable)	2 – Project documentation analysis 6 – Flight scheduling – according to favourable weather forecasts	3 – Asset owners’ entities – inspections acceptance/authorisations granted 7 – Owners’ entities information – flight date information and approval	4 – Airspace use authorisations – request for flight authorisation from NARA* (if applicable) 8 – Flight path – establishing a suitable flight pattern
Flight operation	1 – Confirmation of flight conditions – according to more accurate weather forecasts	2 – Flight checklist – in loco and before take-off, a flight checklist is confirmed	3 – During flight – flight parameter check; response to emergency situations	

*National airspace regulatory authorities.

be used falls mainly in the amateur (“hobby”)/professional/commercial groups, whose variation depends on the rigour required for the work to be carried out as well as the cost to be borne for that purpose.

Typically, the global drone system includes the aircraft (Figure 1), control stations (ground support equipment) and data and communication links. Although many commercial alternatives are available, the basic components and operating principles are generally quite similar among most available versions.

Within the construction sector, drones are already emerging as a preponderant trend in the use of advanced tools. Therefore, the use of drones in CI is thus a relatively new concept and many stakeholders in the sector

are still discovering its applications, which, according to literature in general, can go through monitoring construction activities, topographical surveys, photography and surveillance, visual inspection in hard-to-reach sites, on-site safety inspection, budgeting, anomaly detection and construction defects, interaction with workers, etc.

In particular, for building (and structure) inspection using drones, great attention has been paid to the active development of building inspection and monitoring systems, which when conducted in a timely manner can significantly contribute to reduce repair costs.

These devices have great potential since they can be inserted in the group of “non-destructive testing” (NDT)-

Table 4: Some photographic results of inspections

“Case A” (High habitational building)	“Case B” (Chimney)
<p>(Adapted from [12])</p>	<p>(Photographs and figures made by the authors)</p>

Table 5: Exploratory case studies with drones – summary of results framed in SIAPME fields

General Asset Management Functions						
3. Real Estate (...)						
Building(s)						
Phase I - Stratification of Information Levels	□ Level 1 - List of Building Elements(s)					
	From the Element Framework					
	1.II. Finishings					
	1.III.1. Coatings					
	1.III.1.1 Vertical Elements					
	1.III.1.1.2 External Surfaces					
		‘Case A’		‘Case B’		
		▼		▼		
ADAPTED STRUCTURE WITH BASIS ON [16] Phase II - Characterisation of Reference State (CRS)	□ Preliminary Inspections					
	□ Record of Inspection Results					
	Physical Condition:	Criterion	Value	Criterion	Value	
		Reasonable	3	Reasonable	3	
		Component with relevant deterioration and affected durability				
	Inspection Event Sheet (IES)	▪ (Brief) Inspection Description				
		Visual inspection on site, using drone, equipped with high resolution camera (for video and photography).				
		▪ Diagnosis Type				
		General or preliminary inspection; Type of assessment obtained: qualitative.				
		Diagnosis	- Brief Description of Pathologies and of Occurrences Level			
			Loss of adhesion of external coating mortar and subsequent detachment; Existence of large areas of cracked coverings.	Mainly localised coating detachments		
			□ Causes			
			Main: lack of maintenance measures - it is a long-standing empty building (it has unfinished interiors and has never had significant human habitation).	Incompatibility of materials and/or possible movements on the support structure (of thermal origin with expansion / retraction, or by natural deterioration or even loss of strength).		
			□ Effects			
		With immediate direct effects (in the elements under analysis) and in the vicinity (in adjacent elements)	For now, only with immediate direct effects on a very small scale / with no apparent relevant consequences.			
		Criticality Analysis	□ Severity Level			
				Moderated	Moderated	
			□ Occurrence Level			
				High	Moderated	
			□ Detectability Level			
		Moderately high	Moderated			
+ Global Evaluation						
Within a tolerable risk						
▪ Recommended actions / prioritisation		Need for total rehabilitation (repair and adaptation to current requirements).		There seems to be a need for constant state monitoring, with particular emphasis on the structure condition, which is why special attention should be given to any alert occurrence.		

type methods, especially for the detection of anomalies/pathologies, damage examination and monitoring of the conservation status. Therefore, in some circumstances, the detection and diagnosis of certain situations can be carried out at a lower cost, faster than the traditional methods and with greater security.

Studies with drones have shown interesting results [10,11,15,19]. In general, researchers have focused on the use of coupled cameras to capture images and videos in HD and sensors or infrared cameras (and 3D scanners) as well as the use of the digital photogrammetry technique for large-scale mapping applications, etc.

5 Presentation of results

Some photographic results of drone inspections carried out in the above cases referred in the paragraph under Section 3.2, are included in Table 4 as well as the definition of a flight pattern for “Case B.”

For the purposes of this study, the analysis of inspection results may fall, for example, within the scope of a BMM process. Thus, resorting to fields of a certain methodology called “information system for automatisisation of

procedures in the building maintenance management” (initials in Portuguese: SIAPME [16]), the results of inspections performed for characterisation of reference state (CRS) of building elements in question are used to fill in the IESs. This will allow the level of conservation status to be recorded, a circumstantial diagnosis to be made, a simplified risk analysis to be established and recommended actions and their prioritisation to be proposed – Table 5. All these information will later be aggregated in a register/tree of building elements’ attributes and associated with an initial strategic maintenance plan – SMP (or adjusted from the CRS).

6 Discussion

An appropriate knowledge about a real estate must go through its descriptive management, thus embracing a portfolio of all elements, which necessarily have to be maintained throughout their lifetime. First, this process involves a “stratification of information levels,” in order to identify the hierarchical position of any element (e.g. for our case studies, “phase I,” in Table 5, partially typifies it). Hereafter, a CRS is accomplished (“phase II”),

Figure 1: Scheme of the main physical parts of drones in general.

initially recording the inspection results (of those which are considered here as “preliminary inspections”), as also moving further to filling a more detailed IES. The “physical condition” appreciation follows a criterion on a scale of five values, in which: “1” – corresponds to “very good,” that is, it treats of a constructive element that performs in a good condition level (physical, structural and functional) and “5” – “very bad,” referring to a constructive element which was detected to be a critical failure(s) (or with significant probability of imminent collapse). For both cases illustrated in Table 4 (“Case A” and “Case B”), it was considered a “reasonable” criterion, as it emerged from our overall assessment after inspections, and so the generic assessment of their physical condition points to components with a relevant deterioration and durability eventually affected – cf. Table 5.

The criteria adopted to identify pathologies and causes were fundamentally based on treatment and technical-theoretical evaluation made on data result of inspections carried out by drones (HD photo and video).

Also, site conditions, the buildings constructive characteristics, the empirical knowledge resulting from inspectors’ day-to-day experience, the resource to expertise literature as well as comparisons with similar cases previously assessed are aspects which are the basis for or helped in establishing a strictest possible diagnosis of causes, in short is described in Table 5. As it can be seen from photographs inserted in Table 4, it was verified that external surfaces of the tall building (“Case A”) present large areas with loss of adhesion of external coating mortar and subsequent detachment as well as the existence of cracking (in general on the location where the coating still remains). In case of the chimney (“Case B”), despite having already been the subject of previous repair, localised coating detachments have now been detected. In general, these pathologies are due to the common degradation phenomena for each type of constructive solutions adopted such as incompatibility of materials and/or possible movements on the support structure (of thermal origin with expansion/retraction, or by natural deterioration or even loss of strength). Situation gets worse over time, as in “Case A,” when either the maintenance is not carried out or it is mainly performed on a reactive basis, or when it is very dependent on the available budgets.

For the purposes of this study, it still seemed important to consider a simple way of theoretical risk analysis which could be drawn from the inspections. It has to be clarified about how ratings were assigned to the different factors considered. Thus, the graduation of (i) “severity level” – ranges from “none” (no noticeable effect at the

level of the component or construction system). For both cases studied, “moderate” was considered, that is, a component that is still globally operational; (ii) “occurrence level” – which depends on a theoretical level of possible manifestation of failure modes, that is, the lowest “remote or unlikely failure” to “very high failure occurs inevitably.” In “Case A,” a “high” level was considered while in “Case B” “moderated” level was considered, thus standing in an intermediate position; (iii) “detectability level” – which here theoretically refers to the greater or lesser capacity for fault detection, ranging from “almost certain” to “absolute uncertainty.” In “Case A,” it was considered “moderately high,” getting a little worse, in “Case B” – “moderately high.”

From a maintenance management perspective, the results from “Case A” analysis point to the need of total rehabilitation (repair and adaptation to current requirements), although this action, when established only at the level of the coating, may not be urgent, since opportunity will certainly be dependent on the satisfaction of other more immediate criteria, possibly related to the remaining construction elements or to the building as a whole. In “Case B,” there seems to be a need for constant monitoring of its state of conservation, with particular emphasis on structural conditions, since any occurrences at this level could have major repercussions on the coating. In both cases, any option (intervention or not) will always depend on the owner’s maintenance policies.

On balance, it seems to have been clearly proven that without the use of drones for the purposes laid down, results would certainly not be obtained quickly, safely and cheaply as they actually were, nor would they most likely lead to greater clarity and enhanced objectivity in their treatment and analysis. Especially with particular relevance for a better diagnosis of each situation and for a simple risk analysis, which despite being simple, could be even more accurate. Thereby, this allows to make a set of intervention recommendations and its prioritisation, comprising greater level of rigour.

7 Conclusion

Two cases of field tests with drones were presented in this study, allowing to verify its adaptability and versatility, within the scope of condition monitoring of building envelope and other type of structures. In fact, both in the case of façade of a tall residential building and in the situation of the chimney, inspection actions carried out using two drones equipped with HD cameras allowed

to get useful evidence essentially related to (i) the possibility of being able to make rapid use of these means, (ii) the excellent manoeuvrability demonstrated by the devices by easily going to places of difficult access, (iii) the possibility of minimising costs related with the operations, (iv) the mitigation of operational risks and (v) the substantial improvement in the quality of final results, especially as a result of the visual clarity allowed by cameras to reveal problems which are often undetectable by the human eye.

Also, from the accomplishment of these inspections, it was possible to rehearse the CRS of elements, thus facilitating the updating (or realisation) of an eventual SMP.

Although this study is mainly related to the use of drones equipped with HD cameras for visual inspection, other opportunities may eventually evolve in order to couple sensors or infrared cameras (and 3D scanners), to use digital photogrammetry techniques or even to make it possible to collect and analyse quantitative data (displacement fields and deformations) which are essential for the assessment of the reliability of structures under observation.

Still it is believed that this study is a useful contribution towards a better clarification on the use of drones for purposes of inspection of building facades and structures in general as well as about the great advantages, all of the associated technology may up come for stockholders of the construction sector.

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