Collecting built environment information using UAVs: Time and applicability in building inspection activities

sustainability

MDPI

Article

Collecting Built Environment Information Using UAVs: Time and Applicability in Building Inspection Activities

Rachele Grosso [1], Umberto Mecca [2,*], Giuseppe Moglia [2], Francesco Prizzon [3] and Manuela Rebaudengo [3]

1 Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy; rachele.grosso@polito.it
2 Department of Structural, Geotechnical and Building Engineering, Responsible Risk Resilience Centre, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy; giuseppe.moglia@polito.it
3 Interuniversity Department of Regional and Urban Studies and Planning, Responsible Risk Resilience Centre, Politecnico di Torino, Viale Mattioli 39, 10125 Torino, Italy; francesco.prizzon@polito.it (F.P.); manuela.rebaudengo@polito.it (M.R.)
* Correspondence: umberto.mecca@polito.it; Tel.: +011-090-5317

Received: 20 May 2020; Accepted: 4 June 2020; Published: 10 June 2020

check for updates

Abstract: The Italian way of thinking about maintenance is too often one-sided. Indeed, it is considered not so much as a useful practice to prevent the occurrence of a fault (ex ante), but as an intervention to solve it (ex post). Analyzing the legislation relating to the construction sector, it can be seen that it does not clearly define the responsibilities, timescales and methods in which maintenance interventions must be planned and carried out. For this reason, this practice is still very weak compared, for example, to the industrial sector, where it is an established practice. Currently, the complexity of reading the maintenance plans drawn up by designers and the considerable costs associated with maintenance operations discourage owners and managers from even carrying out preliminary inspection operations. This research aims to stimulate these stakeholders to carry out inspection operations regularly, highlighting their costs and benefits. In particular, working on a case study in Piedmont, the costs of visual inspections carried out in the traditional way are compared with those that would be incurred if unmanned aerial vehicles (UAVs) were used. Finally, the collateral benefits of inspections carried out with UAVs are highlighted.

Keywords: maintenance plan; preventive maintenance; buildings inspections; inspection costs; UAV

1. Introduction

If we consider the collection and use of systematic data on maintenance operations in buildings, "[. . .] a theoretical vacuum is created in the building sector [...]: just as, more generally, quality theories, so maintenance and especially scheduled maintenance, are now consolidated for household appliances rather than for buildings" [1]: there is no national database or extensive research on the subject; some recent data concerns in particular the maintenance of infrastructures, which are those components with the greatest negative impact in case of breakdown/incidental negative event [2,3]. If there was an available database of the interventions carried out, it would certainly be useful for preliminary studies on scheduled maintenance. How can information be collected without imposing new regulatory requirements on the asset managers/owners? How to make the built environment information available and "attractive" also from an economic point of view [4]? It is therefore necessary to change the logic of the maintenance intervention, exploiting low costs and promoting data collection. This paper studies time and costs of using drones for the gathering of information related to the maintenance of the building envelope, in particular to support the operations of visual inspection, foreseen to be part of the maintenance plan of public and private buildings. Certainly, drones can also be used for the collection of information at the "enlarged" urban scale, in particular in transformation processes that require preliminary economic assessments or aim at increasing the safety in urban spaces [5,6].

The term "drone" refers to the device that the Italian Civil Aviation Authority (ENAC) defines as a system consisting of an aircraft (unmanned aerial vehicle—UAV) and the related components for the control and command (control station) by a remote pilot, carrying no people on board and being normally used for purposes other than recreation and sports. In order to provide a specific theoretical framework to the theme, we decided to make a research on indexed databases looking for the terms "UAV", "maintenance" and "inspection" at the same time. The reasons for this preliminary research are that we would like to have an overview of the scientific documents that have been written so far. We obtained 210 outcomes; analyzing them, it is clear that this theme started to be treated consistently since 2012 and that the largest number of these publications has been reached in 2019 with 55 documents (Figure 1). Most of the documents come from China, the United States of America and from Italy (Figure 2). The subject area on which it has been written most is "engineering", with 33.1% of the published documents, followed by "computer science", with a percentage that is about 20.5% (Figure 3). Focusing on the engineering subject area, the article topics are from time [7], inspection of bridges [8,9] and other hard-to-reach complex structures/infrastructures [10–12].

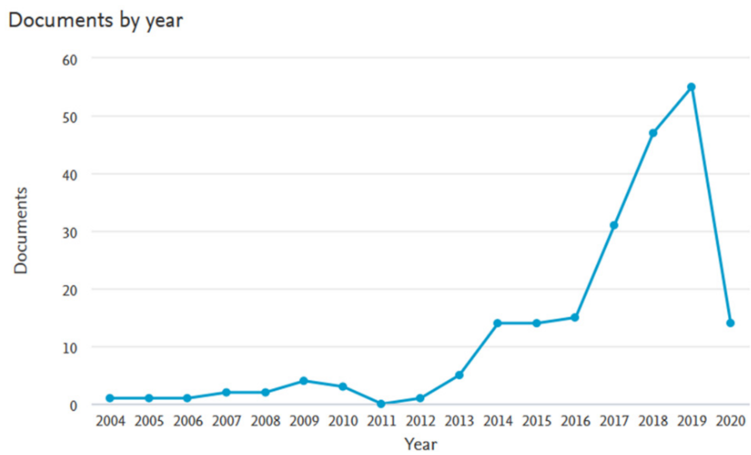

Figure 1. Documents by year (source SCOPUS; www.scopus.com).

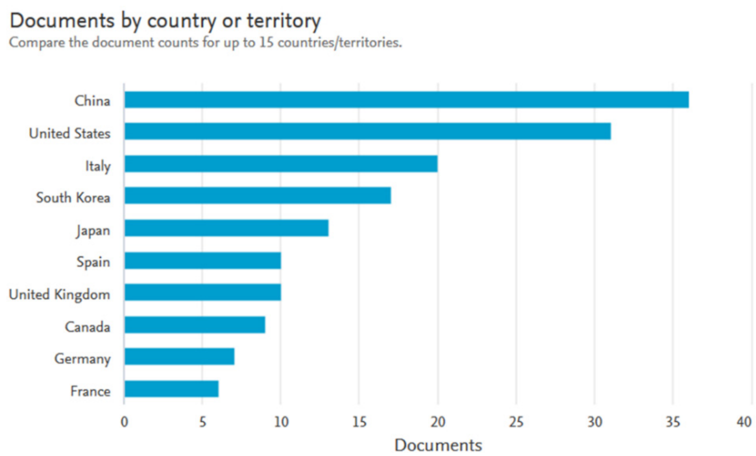

Figure 2. Documents by country or territory (source SCOPUS; www.scopus.com).

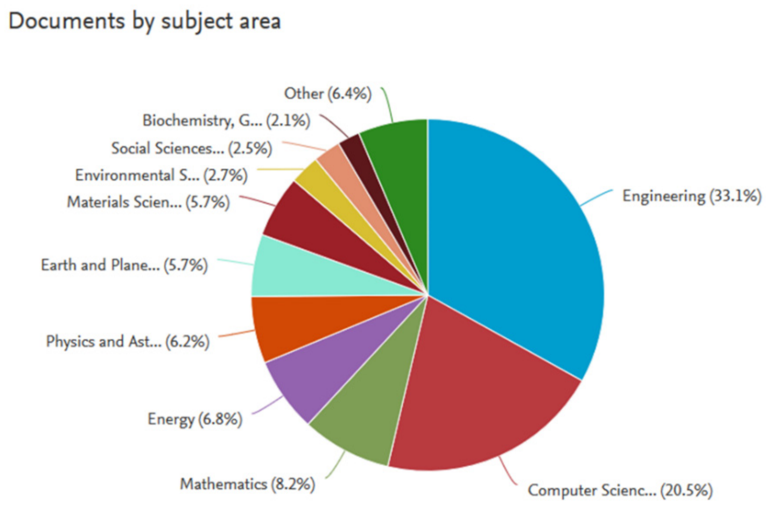

Figure 3. Documents by subject area (source SCOPUS; www.scopus.com).

The first examples and uses date back to the second half of the 19th century, in the field of warfare in Europe (Zhou and Gheisari, 2018) [13], and for this purpose they have been produced and improved during the 20th century. The fast technological evolution of the 2000s then gave rise to a new market in the civil field that began to develop in a parallel way with the traditional warfare market, with recreational, sports and professional purposes (Hallermann and Morgenthal, 2013) [14]. This sudden development of the drone's market has brought their use in many and varied application sectors, leading to the evolution of some professionals (Lavalle, 2016) [15] and the training of new types of experts.

Our research focuses on building applications, showing that the visual inspections of the built-up could be done either in a traditional way or with the UAVs and in particular, it assesses the differences of costs between the two different techniques. By "traditional way" we mean through the use of vehicles, equipment and methods that usually are used in the construction sector. For example, the state of maintenance of a gutter can be detected in the traditional way using a ladder to reach it or from the ground using a UAV. Finally, this research shows what kinds of materials and reports are drawn up, for tracking, after the survey, in the case it is decided to do an inspection in a traditional way or with the use of a UAV.

This paper analyses the possibility of using drones for building maintenance activities, a kind of application which is not significantly widespread so far. The following specific literature review on the subject will better clarify the boundaries of such application and the relevant regulatory framework. In this paragraph the presence of a gap between rules and their actual application emerges. In fact, the real estate assets present in the national territory are mostly composed of existing buildings that were built before the implementation of the just mentioned laws; therefore, many situations are non-compliant, with no background documents dealing with the overall maintenance of the building, and no inspection programs for the different technological components belonging to the construction. For this reason, maintenance works are often carried out after the damage has occurred, i.e., with the urgency given by the need to restore the functionality of the corrupt component. Therefore, the preventive inspections that should be done to verify the correct functioning of the various technological components, are often neglected; only the controls on the heating/cooling systems are carried out systematically, probably because, for these kinds of inspections, the responsible parties and potential penalties are clearly identified.

According to the authors, the main cause for the lack of the buildings' inspections is that users do not understand how useful they are in preventing building's component failures. Another typical situation is the one in which, despite inspection activities being carried out, no documentation on them remains, and therefore it is not possible to assess the loss of efficiency due to a progressive degradation of an element over time. Normally, when they are properly carried out, controls over building's components, in both public or private buildings, are performed by competent operators of specialized companies through visual inspections and specific operations.

Literature Review

The scientific production on UAV application in the construction sector was systematically analysed. Zhou and Gheisari's (2018) [13] exploration of peer-reviewed bibliographic databases offers an interesting picture of the last 10 years; a growing number of publications are identified, and the publications are classified by Zhou and Gheisari (2018) [13] into five main topic categories: building inspection, damage assessment, site surveying and mapping, safety inspection and progress monitoring. Another interesting reflection comes from Li and Liu (2019) [16], whose literature review on the topic of UAVs' applications in construction management led them to argue that it can still be seen as a new and innovative technology, as still relatively few research papers have been published, while its application increased faster in recent years. Their review also confirms that UAVs are going to play even more important roles in the future. From the observation of this potentially expanding phenomenon, the present research aims at investigating the causes of such apparent success, specifically in relation to the field of inspections of the built environment with UAVs, which is the most widely discussed topic in the academic field (Figures 4 and 5).

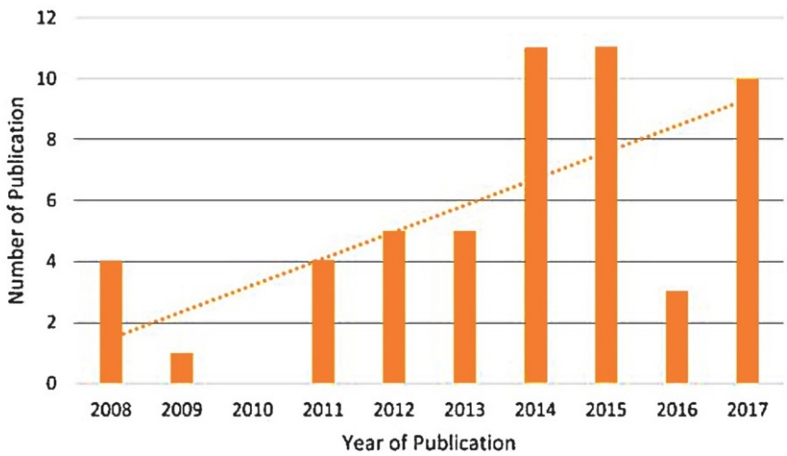

Figure 4. Number of scientific publications on unmanned aerial vehicle (UAV) applications in construction. (Source: Zhou and Gheisari, 2018) [13].

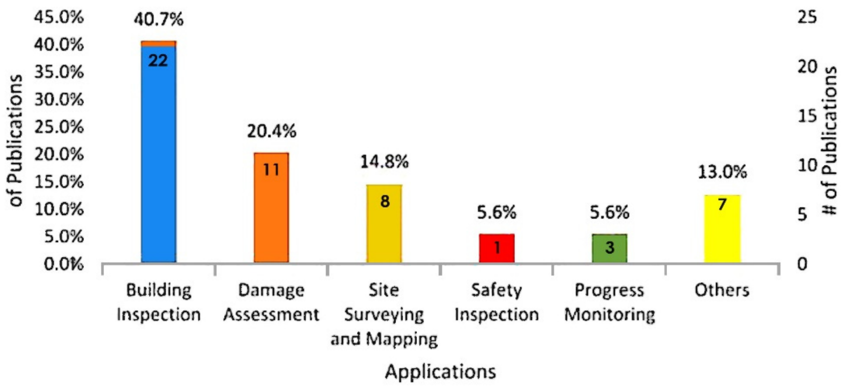

Figure 5. Number of items by type of UAV application in construction. (Source: Zhou and Gheisari, 2018) [13].

Summarizing the advantages gathered from the state of the art analysis, it can be stated that they mainly refer to the reduction of time and costs, the increase of accessibility and the extension of the concept of interoperability in favor of the various operators of the sector, and, consequently, a greater effectiveness in carrying out the operations. This position, shared by the analyzed authors, emerges mostly from papers presenting real case studies, including: a description of the application context (industrial buildings, architectural heritage, infrastructure, residential buildings, and school buildings are the most common); the study of the relative difficulties and operational advantages; the report on the technological equipment used (UAV, camera, thermal chamber ...) and its technical specifications; some discussion about the accuracy of the obtained results (definition of images, point clouds' compactness, processing times of the collected data, drone's performance in relation to its price/weather conditions) compared to the traditional methodology.

For example, Serrat et al. (2019) [17] propose an operational inspection sheet as part of a collaborative approach for the implementation of drones in visual inspections of urban facades and they bring out the need for studies that, in parallel, complement the experiment with more detailed cost and time analysis. Hallermann and Morgenthal (2013) [14] support the use of drones for structural inspections of large infrastructures, often hard to access, as opposed to conventional methods, which require the use of large under bridge units, special elevating platforms or scaffoldings, as well as trained operators, and involves high logistical efforts and significant operational and safety costs. Furthermore, the authors argue that, by using the traditional methodology, we end up generating a gap between the operational step—in which specialized workers are in charge of information acquisition—and the evaluation one—in which the charged engineer draws his conclusion over data he did not personally collect. Many authors, then, underline the advantage given by the automation of procedures. For example, Moore et al. (2018) [18] propose an application for the transition from a "reactive inspection approach"—maintenance operations brought after damage has occurred—to a "proactive" one, presenting the case of maintenance of university campus buildings and their HVAC components. Mauriello and Froehlich (2014) [19] claim the dramatic lowering of operational costs brought by the installation of thermal cameras on drones for the 3D-reconstruction and thermal profiling of buildings. Ferrante and Garnero (2016) [20] reflect about the possibility of using drone technology for cadastral activities and the possibility of introducing it within the procedures of Italian Cadaster conservatory. To support the purpose of this research, this last contribution was particularly interesting, mainly for the close examination proposed of the Italian context (regulatory and operational framework and characterization of the technological level reached in this field by the professionals involved).

The following table summarizes the main strengths and weaknesses declared by the analyzed authors, in the form of a strengths, weaknesses, opportunities, and threats (SWOT) analysis (Table 1).

Table 1. Strengths, weaknesses, opportunities, and threats (SWOT) analysis.

Strengths	Weaknesses
"Inspections with the assistance of UAVs can visualize areas of a building's exterior where it is difficult to access or poses a safety risk to the inspector." (Moore et al., 2018) [18] "Collect data on otherwise impossible or difficult areas." (Mauriello et al., 2014) [19]	Reduced battery life (10 min–30 min) resulting in frequent flight interruptions for battery replacement (Hallermann et al.,2013) [14]
"Inspections could be conducted more frequently and faster than the traditional method." (Moore et al., 2018) [18]	Longer times for data processing (Zhou et al., 2018) [13]
"It is possible to embed a live stream from the thermal camera onto the flight screen of the application. This addition will give the pilot feedback from the thermal camera in real time. This could greatly increase performance during inspection and prevent any subsequent flights if any significant damage is found with the thermal images." (Moore et al., 2018) [18]	
"Dramatically lowering the cost of data collection through automation." (Mauriello et al., 2014) [19]	
Opportunities	**Threats**
"It would be necessary to complement the experiment with a more detailed cost and time analyses." (Serrat et al., 2019) [17]	Restrictions on professional activity—Restrictive ENAC regulation on flight procedures. (Ferrante et al., 2016) [20]
"Rooftop inspections using human inspectors is not always a viable option depending upon the type of building and damage." ... "In inspections of buildings with no rooftop access, human inspectors use ladders to reach the inspection area, which is a significant safety risk to inspectors." (Moore et al., 2018) [18]	Automatic flight termination systems (to meet safety requirements) are not yet optimal and would require technological advancement. (Zhou et al., 2018) [13]

With regard to the design and planning of the maintenance activities to be carried out during a building's life-cycle, the mandatory regulation imposes different requirements, depending on whether it is a public or private asset, or both. In order to conclude a relevant literature review, an operational-based summary of the complex Italian system of requirements regarding maintenance documents has been done.

Legislative Decree no. 81 of 9 April 2008, as amended and supplemented, the "Consolidated Text on health and safety at work", b) letter, Article 91, requires that the coordinator for design, whether public or private, draws up not only the safety plan of the work, but also a document suitable for building's technical description, the building file. The latter is divided into three chapters and, in particular, in the second one, the regulation requires the identification of the risks, the preventive and protective measures that should be endowed with the building, as well as the auxiliary ones, for the subsequent foreseeable interventions on the same building, such as ordinary and extraordinary maintenance, and for the other subsequent interventions already scheduled. This file is drafted during the design stage and may be subject to modification during the execution stage, according to the actual evolution of the works. The customer must keep it updated over time, with all incurred changes. In case it is necessary to undertake renovation work on existing buildings, which are already endowed with a building file, and in case the designation of a design coordinator is required, this one is the professional in charge of updating the above-mentioned document [21].

The building file, if present, must also be coordinated with the maintenance plan for the building and its components. Indeed, the Presidential Decree no. 207 of 5 October 2010, as amended and supplemented, the "Regulation for the execution and implementation of Legislative Decree No 163 of 12 April 2006", requires this document to be provided only for public works. This regulation, in the articles still in force, and in particular with article 38, provides that, for new public works, the maintenance plan must be drawn up in accordance, and as an attachment to the executive project, and it must consist of: the user manual, the maintenance manual and the maintenance program [22].

Finally, with regard to the load-bearing structures of buildings, both public and private, Circular no. 7 of the Superior Council of Public Works of 21 January 2019 provides (paragraph 10.1) that the structural executive plan must be accompanied, among other documents, by the maintenance plan. This must provide the plan and schedule for the maintenance activity, taking into account the executive design documents of the entire work, in order to ensure over time functionality, quality characteristics, efficiency and economic value of the completed construction. This plan, coordinated with the general construction plan (if existing) consists of a user manual, a maintenance manual and a maintenance program for the structures [23].

2. Research Methods

A recent publication by a national research institute [2,24] shows how much Italy has invested in ordinary and extraordinary maintenance of bridges, viaducts, roads, tunnels and buildings between 2010 and 2018. The amount is 8 billion euro per year. Italy is a country in which the built heritage is old and shows signs of aging (even early), so it is clear that maintenance costs can increase year after year. According to the above-mentioned report, 58.7% of the buildings, or 7.2 million, are over 50 years old and 24% of these have poor or very poor health. Investments in new buildings are not comforting either: in the last nine years 50% of private constructions and 34% of public works have suffered unexpected declines [2].

In order to encourage both the fulfillment of these activities and the drafting of the relevant final report, in the present application it has been assumed to separate the technological components' inspection from the visual ones, and to perform all of them by means of a UAV.

In this way, the visual controls over the building's envelope could be carried out in a single inspection operation, carried out by an expert in the construction sector who is qualified to pilot drones. Once the UAV-aided visual inspection is completed, it is also assumed that the commissioner can choose between four different levels of output options, depending on the analyses carried out by the expert on the photogrammetric material resulting from the inspection. However, even though all four levels provide for the restitution of photographs and videos obtained with the UAV during a single mission, they differ by the amount of measurement operations carried out by a dedicated desk job following the onsite survey. Indeed, some basic operations of measurement and numerical estimation of the surfaces on which maintenance operations are needed, are provided directly from the photos in level 1. Summarizing the four options, with the first one (#1) no further quantitative analysis will be carried out after the inspection; with the second one (#2) up to 25% of the material obtained will be analyzed; with the third one (#3) up to 50% will be analyzed; finally, with the fourth (#4) a complete qualitative-quantitative analysis will be carried out, i.e., it will be systematically analyze up to 100% of the material. The aim of this work is to highlight the differences between the costs of visual inspections carried out in the traditional way, i.e., through the use of manpower and means necessary to ensure accessibility to all components of the outer shell (lift baskets, mobile scaffolding, etc.), and those carried out by a professional using a UAV. These differences are empirically derived from a case study, represented by a real maintenance plan analysis. In particular, we focused on inspection costs, by calculating the overall expenditures of those operations that can be carried out by visual investigation. In this way, we were able to compare them with those that can be carried out through a UAV. Finally, the different options were compared, with the aim to highlight the differences between the costs and, above all, the degrees of quantitative analysis of each operation.

Case Study

In order to carry out the above-mentioned analyses, the case study presented in a previous research (Rebaudengo and Piantanida, 2018) [25], always on the maintenance subject, was used. It consists of a private office building of about 2500 square meters, located in Turin, composed of a basement and five floors; the green roof is accessible only for maintenance operations by means of a specially prepared trapdoor. It is an isolated building in a consolidated urban context. There is no sensitive infrastructure nearby, so we can assume that the drone's flight can be authorised. Moreover, in order to safely carry out these maintenance operations, there is a lifeline along the edge of the roof. The special feature of the building is the facade overlooking the contiguous road; this facade is composed of backward terraces, consisting of real vases, called "flowerpots" in the maintenance plan. This system is possible thanks to the material and to the technology used for the load-bearing structures, i.e., through the means of reinforced concrete bearing elements that step backward with the increasing of the height of each floor. On the elevation facing the road, south-oriented, appropriate sliding sun screens are designed, which are composed of some adjustable photovoltaic elements. The elevation overlooking the courtyard is less articulated than the previous one and has only one projection given by the vertical distribution compartment: this facade is ventilated and covered with Alucobond and aluminum layers.

In the interior of the building, the air conditioning system is ensured by fan coils, i.e., terminals of the system that use an air-water heat pump as a generator. As far as the air exchange is concerned, no system is provided, thus entrusting it to infiltration and exfiltration through windows and doors. The rainwater disposal system consists of gutters and drainpipes that convey the water to the ground, where, through a system of pipes, it is directed to appropriate disposal tanks; the same function is performed by the grids and the manholes located on the driveway and on the courtyard.

3. Results and Discussion

The maintenance plan of the case study consists of 43 categories for which there are foreseen appropriate inspection and maintenance operations. For the analysis, only the part concerning inspection operations (IO) was considered, differentiating between: inspections that can be carried out only in a visual way (VI) and inspections that require additional operations, such as the disassembly of a component in order to view the layer below. Together, these two inspection ways constitute the traditional complete inspection (T-CI). We decided to split up all maintenance operations because we wanted to compare the costs of visual checks when they are carried out in the traditional way (T-VI) and when they are carried out using a drone (UAV-VI). By examining the elements that made up the plan, we selected only those for which it is possible to carry out, at least in part, VI operations, for a total of 17 out of 43 items. For each of them, we estimated the VIs percentage of incidence related to traditional inspections; thus, showing that they are about the 22% of the total (Table 2).

Table 2. Building elements for which it is possible to split-up the costs relating to visual inspection operations only from those for full inspection.

Elements	T-CI costs [€]	VI percentage rates [%]	T-VI costs [€]
Alucobond coating	25.73	50	12.86
Aluminium coating	25.73	50	12.86
Joinery on the flowerpots side	9.90	25	2.48
Joinery	9.90	25	2.48
Sliding sun screens on the flowerpots side	32.16	25	8.04
Sliding sun screens	32.16	25	8.04
Ventilated walls facing the street and the backyard	2.86	50	1.43
Ventilated walls in Alucobond	2.86	50	1.43
Glazed facades	1.70	25	0.43
Porphyry baseboards	5.72	100	5.72
External porphyry flooring	4.28	100	4.28
Roof garden	23.86	30	7.16
Flat roof railing	10.97	100	10.97
Gutters and rainwater	40.01	100	40.01
Water outlet grids	40.02	50	20.01
Waterproofing layer	11.50	60	6.90
Flowerpots	16.46	100	16.46
VI percentage mean	-	**22**	-
Net cost + Company's profits + business overheads	**295.82**	-	**161.55**

(T-CI = traditional complete inspection); VI = inspection that can only be carried out in a visual way; T-VI = visual checks when carried out in the traditional way).

The cost of the 43 element T-CIs is about € 680.00, which is the labour-related value, the freight and transport costs, incremented by the business profits and the general business expenses. For the T-VI, from the previously calculated percentage weights, we estimated an expenditure of about 162.00 €, i.e., 24% of the total costs (43 elements). No documentation of these inspections remains after the survey, since no output documents are drawn up at the end of the inspection. The same VIs can also be carried out with a UAV, but in this case, the cost estimation cannot be defined with a price list, as these operations only now begin to appear on the market. Therefore, some market surveys were carried out in order to determine the general cost. Among the initial costs that a professional must bear once decided to start carrying out UAV-VI, we identified: the costs of ENAC-approved training courses, including those for medical examinations and those for the qualification exam; the costs of purchasing a UAV and the authentication to ENAC; the costs of purchasing a PC with sufficient characteristics for the subsequent analysis operations. An amortization rate of 20% per annum was applied to the sum of these costs over a period of 5 years. In addition, each year additional operational cost will be incurred for the renewal of the UAV's insurance and of the license of the photogrammetric program for carrying out the operations of quantitative estimation of the damaged portions of the elements (Tables 3 and 4).

Prudentially, we estimated that a professional uses about 30% of his working time to carry out inspection operations by a UAV, for a total of 80 days a year. From these hypotheses, developing an evaluation over a period of five years, it was possible to calculate an hourly average cost that is about 9.50 €; that will go under the item named "equipment amortization". To carry out the UAV-VI, two operators are always necessary: the professional who does the inspection and a collaborator who monitors the UAV during the flight with the aim of minimizing the risk of any collisions with objects of various kinds. The hourly rate of the two operators, net of value-added tax (VAT), was estimated at 60.00 € for the professional and 30.00 € for the employee; the values come, once again, from a local professionals' market survey. For the inspection of a facade of a small-medium sized building (5–10 above ground floors) an actual flight time of the UAV between 10 and 20 min is estimated.

Table 3. Initial investment costs list.

Elements	Costs * [€]
Medical examination	150.00
Foundation course	500.00
ENAC practical examination	150.00
Critical operations course	680.00
ENAC practical examination	150.00
UAV authentication	244.00
Mavic 2 Pro + Fly more kit	1898.00
Personal Computer	1441.59
Total amount	**5213.59**

* data from market surveys.

Table 4. Operating costs list.

Elements	Costs * [€/year]	Costs * [€/(5 years)]
Insurance	500.00	-
Pix 4D mapper	3990.00	-
Flight licence renewal	-	350.00
Total amount	**4490.00**	**350.00**

* data from market surveys.

Therefore, due to our case study's features, we assumed that the two operators could work on this for about an hour, also including the time needed for their shift to the site of the UAV mission. Indeed, in the hypothesis that the surveyor starts from the center of Turin they can reach between 30 min and 1 h of time almost all the places in a range of 50 km (Figure 6).

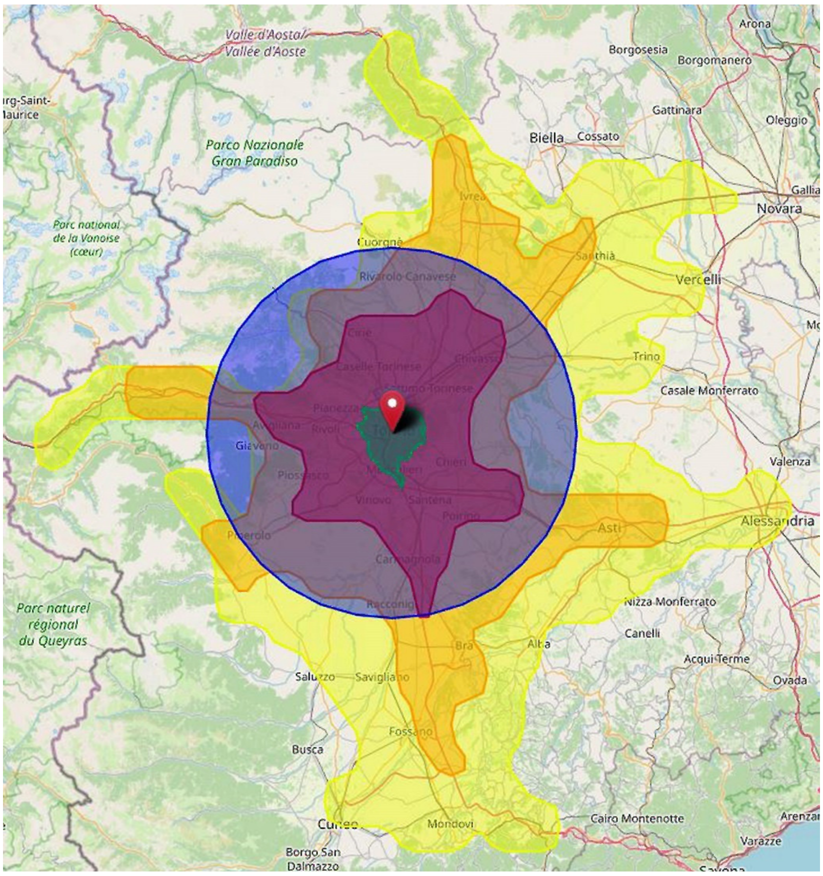

Figure 6. Representation of the travel times of a motor vehicle departing from the center of Turin. The different colors represent different travel times: yellow 1h, orange 45", red 30", green 15". The circle gives an idea of the distance because it has a radius of 50 km (source OWLAPPS; http://www.owlapps.net/application-geomarketing) [26].

Once the survey and the inspection operations have been completed, as it is shown above, the client will be able to choose between four different options for qualitative and quantitative analysis of the digital material obtained during the survey. The different options correspond to different post-production times. Not considering option #1, for which no complex measurement operations are foreseen after the survey, it is estimated that option #2 requires 2.5 h of analysis, option #3 requires 4.5 h and finally option #4 requires 9 h. It is also believed that these analysis times are equally shared between the professional and the co-worker. From considering freight, transport, and manpower costs, in dependency on the time required for the various operations, the technical costs of the controls have been obtained. Adding to the latter the company's profits and the business overheads, the total costs of the four options have been determined (Tables 5–8).

Table 5. Price analysis for option #1.

Elements	Units	Co-Worker	Professional	Total
Manpower	n°	1.00	1.00	2.00
Inspection time	H	1.00	1.00	2.00
Postproduction analyses time	H	0.00	0.00	0.00
Hourly fee	€	36.60	73.20	109.80
Manpower cost (inspection)	€	36.60	73.20	109.80
Manpower cost (postproduction analyses)	€	0.00	0.00	0.00
Equipment amortization	€	9.50	9.50	19.00
Net cost	€	46.10	82.70	128.80
Total amount (with business overheads)	€	57.30	102.80	**160.10**

Table 6. Price analysis for option #2.

Elements	Units	Co-Worker	Professional	Total
Manpower	n°	1.00	1.00	2.00
Inspection time	H	1.00	1.00	2.00
Postproduction analyses time	H	1.13	1.13	2.25
Hourly fee	€	36.60	73.20	109.80
Manpower cost (inspection)	€	36.60	73.20	109.80
Manpower cost (postproduction analyses)	€	41.18	82.35	123.53
Equipment amortization	€	9.50	9.50	19.00
Net cost	€	87.28	165.05	252.33
Total amount (with business overheads)	€	108.48	205.16	**313.64**

Table 7. Price analysis for option #3.

Elements	Units	Co-worker	Professional	Total
Manpower	n°	1.00	1.00	2.00
Inspection time	H	1.00	1.00	2.00
Postproduction analyses time	H	2.25	2.25	4.50
Hourly fee	€	36.60	73.20	109.80
Manpower cost (inspection)	€	36.60	73.20	109.80
Manpower cost (postproduction analyses)	€	82.35	164.70	247.05
Equipment amortization	€	9.50	9.50	19.00
Net cost	€	128.45	247.40	375.85
Total amount (with business overheads)	€	159.66	307.52	**467.18**

Table 8. Price analysis for option #4.

Elements	Units	Co-Worker	Professional	Total
Manpower	n°	1.00	1.00	2.00
Inspection time	H	1.00	1.00	2.00
Postproduction analyses time	H	4.50	4.50	9.00
Hourly fee	€	36.60	73.20	109.80
Manpower cost (inspection)	€	36.60	73.20	109.80
Manpower cost (postproduction analyses)	€	164.70	329.40	494.10
Equipment amortization	€	9.50	9.50	19.00
Net cost	€	210.80	412.10	622.90
Total amount (with business overheads)	€	262.02	512.24	**774.26**

Summarizing the findings of the of the different options, it is possible to highlight how the times and costs change considerably according to what the client intends to obtain from such operations. As reported in Table 9 the costs of T-VI and UAV-VI are comparable and have the same order of magnitude, while options #2, #3, and #4 have higher costs. However, only if inspections are carried out by means of UAV will it be possible to achieve technical documentations from the survey operation, i.e., photographic and video material; moreover, only in such cases will it be possible to obtain quantitative measurements of the surfaces of the elements that need maintenance operations.

Table 9. Summary comparison table.

	T-CI	T-VI	UAV-VI O. #1	UAV-VI O. #2	UAV-VI O. #3	UAV-VI O. #4
Times [h]	12.15	0.93	2.00	4.25	6.50	11.00
Costs [€]	678.58	161.55	160.10	313.64	467.18	774.26
Photos – Videos	NO	NO	YES	YES	YES	YES
Report	NO	NO	NO	YES	YES	YES

The simulations assumed so far are derived from a survey that was carried out by a real estate company to detect the state of maintenance of a building in the outskirts of Turin (Figures 7 and 8). Using a drone, a series of photographs was collected that allowed the designers to understand the real state of the roof and of the facades. The survey was conducted before the renovation works by three workers (an architect, a surveyor and a worker) and it took about three hours on the field, also including the time to reach the area. The post-production time was about 50 min and it consisted only in the analysis of the photograms and of the video. As far as economic data are concerned, it was not possible to divide them by the global costs of the renovation design service. Nevertheless, these inspection data were very useful to determine the time of the options above hypothesized (Table 10).

Table 10. Summary of inspection data.

Elements	Units	Co-Worker	Professional	Total
Manpower	n°	1.00	2.00	3.00
Inspection time	h	3.00	3.00	9.00
Postproduction analyses time	h	0	1	1

Figure 7. Picture that shows the facade of the inspected building. The frame was extrapolated from the video registered by the UAV's camera (source: real estate company archive).

Figure 8. Picture that shows the roof system of the inspected building. The frame was taken with UAV's camera (source: real estate company archive).

4. Conclusions and Research Future Developments

The purpose of this article was to empirically test the economic and general advantage (documental availability about the facility state), obtainable from the use of the drones in the field of maintenance of the built environment, in particular its potential role for visual inspections. Despite the fact that many scientific articles support the topic under analysis, as it is shown in the state of art, up to now the subject has never been studied in depth from the economic perspective—at least in the most recent literature, to the knowledge of the authors. Indeed, any analysis of precise data referring to a case study that aims to verify the actual economic convenience of using a drone for buildings' inspections was not found.

The research aims to empower inhabitants, owners, workers, professionals, property administrators, etc. on the positive effects of preventive maintenance by providing an economic perspective on the topic. In particular, our intended purpose was to show how investing in the latest technological innovation of this field (UAV-aided scheduled maintenance), actually implies low costs in relation to the general perception surrounding preventive maintenance actions, and with respect to the great amount of data that can be derived from this kind of operations.

This study's main limitation, in the achievement of the stated goal of increasing responsibility by unveiling the economic aspect of scheduled maintenance, lies in its theoretical nature. Consequently, in order to provide it with a stronger empirical grounding extracting actual information about building's maintenance costs, a test, consisting of application, monitoring and evaluation applied to a reliable period of time and a consistent number of units, would be required.

It is clear the advantage of the operators (involved company and professionals shown in Figure 9), who are finally in the best working conditions: having available, in digital format, the building materials. Less positive effects are perceived by the building manager (a more complete operator who, with the systematic data archive, favors more rapid alternations without loss of information) and even more by the owner, the only one involved in the new expenditure. In order to improve the diffusion of good practices promoted by this research, it is necessary, however, to test our assumptions on two similar buildings, in order to verify the economic savings in terms of future maintenance and the related cost of technical services. Moving on in this way to the urban scale, step by step, it could "indirectly" provide information to the public space as well.

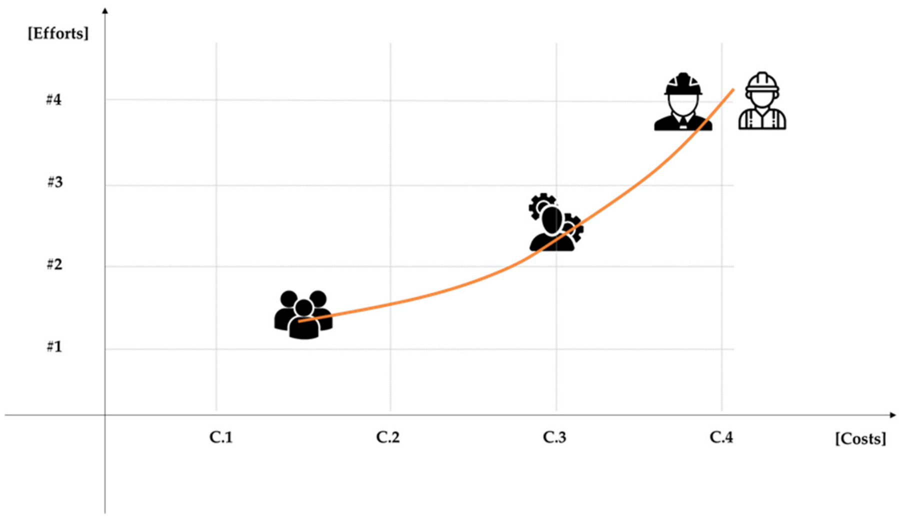

Figure 9. Cost-effectiveness perception of involved stakeholders.

The authors have used SWOT analysis as a methodology for a preliminary approach to the problem. It allowed an effective synthesis of the advantages and disadvantages deriving from such implementation. If we consider, for extraordinary maintenance, an average annual expenditure per building of about 4300 € [27], it is possible to note that the average cost of visual checks is between 4–18% of this expenditure, depending on the method by which they are carried out. Moreover, if the visual inspection with a drone was performed annually it could be assimilated to the activities referred to in option 1, with a significant reduction of the cost incidence (less than 4% of the annual expenditure). Currently, the most evident critical points concern the flight authorization phases and the limitation to visual inspections which are only a part of the preliminary maintenance operations.

A future development of this work could be the application of the same economic analysis on buildings with different uses (infrastructure, factories, cultural heritage, disused industrial areas) or facade technical solutions [28] to discover the most advantageous field of application. Other possible developments could be the inspection of full areas at the same time, or the realization of automatic inspection methods using automatic UAV flight routes.

In addition, a reverse research could be carried out which, starting from a—case study, will determine the parameters which most influence the economic benefit of professionals and which are the obstacles of the transition from traditional to UAV-based procedures. Lastly, with the data collected by the UAV's survey, a digital model of the city could be created [29], which could be used—on a building scale—by asset or building managers or—on an urban scale—by local authorities and administrations, in order to have an overview of the continuous transformations of the built environment.

Author Contributions: Conceptualization, M.R., G.M. and F.P.; data curation, U.M.; formal analysis, U.M. and M.R.; investigation, R.G.; supervision, G.M. and F.P.; writing—original draft, U.M.; writing—review and editing, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Talamo, C. *Procedimenti e Metodi Della Manutenzione Edilizia—Vol. II—Il Piano di Manutenzione, 2011*; Sistemi Editoriali; Gruppo Editoriale Simone: Pozzuoli, Italy, 2011.
2. Redazione EdilTecnico. Manutenzione Delle Infrastrutture e Patrimonio Immobiliare, il Buco Nero è Qui. Available online: https://www.ediltecnico.it/69961/manutenzione-delle-infrastrutture-e-patrimonio-immobiliare-il-buco-nero-e-qui/ (accessed on 5 June 2020).
3. CRESME. Una Nuova Edilizia Contro la Crisi, Quaderni di Symbola. 2017. Available online: www.cresme.it/doc/rapporti/rapporto-cresme-symbola-2017.pdf (accessed on 5 June 2020).
4. Carbonara, S.; Stefano, D. An Operational Protocol for the Valorisation of Public Real Estate Assets in Italy. *Sustainability* **2020**, *12*, 732. [CrossRef]
5. Troisi, R.; Alfano, G. Towns as Safety Organizational Fields: An Institutional Framework in Times of Emergency. *Sustainability* **2019**, *11*, 7025. [CrossRef]
6. Sdino, L.; Rosasco, P.; Lombardini, G. The Evaluation of Urban Regeneration Processes. In *Regeneration of the Built Environment from a Circular Economy Perspective. Research for Development*; Della Torre, S., Cattaneo, S., Lenzi, C., Zanelli, A., Eds.; Springer: Cham, Switzerland, 2020. [CrossRef]
7. Jordan, S.; Moore, J.; Hovet, S.; Box, J.; Perry, J.; Kirsche, K.; Lewis, D.; Tse, Z.T.H. State-of-the-art technologies for UAV inspections. *IET Radar Sonar Navig.* **2018**, *12*, 151–164. [CrossRef]
8. Lee, J.K.; Kim, J.O.; Park, S.J. A study on the UAV image-based efficiency improvement of bridge maintenance and inspection. *J. Intell. Fuzzy Syst.* **2019**, *36*, 967–983. [CrossRef]
9. Reagan, D.; Sabato, A. Email Author, Niezrecki, C. Feasibility of using digital image correlation for unmanned aerial vehicle structural health monitoring of bridges. *Struct. Health Monit.* **2018**, *17*, 1056–1072. [CrossRef]
10. Sudevan, V.; Shukla, A.; Karki, H. Current and future research focus on inspection of vertical structures in oil and gas industry. In Proceedings of the 18th International Conference on Control, Automation and Systems ICCAS 2018, PyeongChang, Korea, 17–20 October 2018; pp. 144–149.
11. Addabbo, P.; Angrisano, A.; Bernardi, M.L.; Gagliarde, G.; Mennella, A.; Nisi, M.; Ullo, S.L. UAV system for photovoltaic plant inspection. *IEEE Aerosp. Electron. Syst. Mag.* **2018**, *33*, 58–67. [CrossRef]
12. Barthelson, K.; Sondhi, P.; Mitra, M.; Darhele, S. Design of a ski lift inspection and maintenance system. In Proceedings of the 2018 Systems and Information Engineering Design Symposium, SIEDS 2018, Charlottesville, VA, USA, 6 June 2018; pp. 64–69. [CrossRef]
13. Zhou, S.; Gheisari, M. Unmanned Aerial System Applications in Construction: A Systematic Review. *Constr. Innov.* **2018**, *18*, 453–468. [CrossRef]
14. Hallermann, N.; Morgenthal, G. Unmanned aerial vehicles (UAV) for the assessment of existing structures. In Proceedings of the IABSE Symposium 2013, International Association for Bridge and Structural Engineering, Kolkata, India, 24–27 September 2013. [CrossRef]
15. Lavalle, C. Come cambia la Professione del Geometra Grazie ai Droni. La Stampa 2016, 10th August. Available online: https://www.lastampa.it (accessed on 18 April 2019).

16. Li, Y.; Liu, C. Applications of multirotor drone technologies in construction management. *Int. J. Constr. Manag.* **2019**, *19*, 401–412. [CrossRef]
17. Serrat, C.; Banaszek, A.; Cellmer, A.; Gibert, V. Use of UAVs for Technical Inspection of Buildings within the BRAIN Massive Inspection Platform. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *471*. [CrossRef]
18. Moore, J.; Tadinada, H.; Kirsche, K.; Perry, J.; Remen, F.; Tse, Z.T.H. Facility inspection using UAVs: A case study in the University of Georgia campus. *Int. J. Remote Sens.* **2018**, *39*, 7189–7200. [CrossRef]
19. Mauriello, M.L.; Froehlich, J.E. Towards automated thermal profiling of buildings at scale using unmanned aerial vehicles and 3D-reconstruction. In Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, Seattle, WA, USA, 13–17 September 2014. [CrossRef]
20. Ferrante, F.C.; Garnero, G. Drones in cadastral applications: Possible uses. *Territ. Ital.* **2016**, *1*, 45–59. [CrossRef]
21. D.Lgs. 09 aprile 2008, n. 81, in Terms of "Attuazione dell'articolo 1 della Legge 3 Agosto 2007, n. 123, in Materia di Tutela Della Salute e Della Sicurezza nei Luoghi di Lavoro". Available online: www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2008-04-09;81!vig= (accessed on 5 June 2020).
22. D.P.R. 05 Ottobre 2010, n. 207, in Terms of "Regolamento di Esecuzione ed Attuazione del Decreto Legislativo 12 aprile 2006, n. 163, Recante «Codice dei Contratti Pubblici Relativi a Lavori, Servizi e Forniture in Attuazione delle Direttive 2004/17/CE e 2004/18/CE»". Available online: https://www.normattiva.it/atto/caricaDettaglioAtto?atto.dataPubblicazioneGazzetta=2010-12-10&atto.codiceRedazionale=010G0226&queryString=%3FmeseProvvedimento%3D%26formType%3Dricerca_semplice%26numeroArticolo%3D%26numeroProvvedimento%3D207%26testo%3D%26giornoProvvedimento%3D%26annoProvvedimento%3D2010&currentPage=1 (accessed on 5 June 2020).
23. CIRCOLARE 21 gennaio 2019, n. 7 C.S.LL.PP, in Terms of "Istruzioni per L'Applicazione dell'«Aggiornamento delle "Norme Tecniche per le Costruzioni"» di cui al Decreto Ministeriale 17 Gennaio 2018". Available online: https://www.gazzettaufficiale.it/eli/id/2019/02/11/19A00855/sg (accessed on 5 June 2020).
24. Ufficio Stampa CNAPP. "l'Italia è Ormai un Paese a tempo; serve un Piano Nazionale Centrato sul Riuso e Sulla Cultura della Qualità delle Costruzioni", April 2019. Available online: http://www.awn.it/component/attachments/download/2179 (accessed on 5 June 2020).
25. Rebaudengo, M.; Piantanida, P. Maintenance of buildings: Italian examples of deviations between planned and incurred costs. In *IOP Conference Series: Materials Science and Engineering, Proceedings of the 2017 2nd International Conference on Reliability Engineering (ICRE 2017), Milano, Italy, 20–22 December 2017*; IOP Publishing Ltd.: Bristol, UK, 2018. [CrossRef]
26. OWLAPPS. Available online: http://www.owlapps.net/application-geomarketing (accessed on 18 May 2020).
27. ISTAT, Istituto Nazionale di STATistica. Spese per Consumi Delle Famiglie. Available online: https://www.istat.it/it/archivio/231145 (accessed on 5 June 2020).
28. Rosasco, P. Economic Benefits and Costs of Vertical Greening Systems. In *Nature Based Strategies for Urban and Building Sustainability*; Butterworth-Heinemann: Oxford, UK, 2018; pp. 291–306. [CrossRef]
29. Moglia, G.; Del Giudice, M.; Rebaudengo, M. The model of the city: Data variety, operability and interfaces. In Proceedings of the DRAWING AS (IN)TANGIBLE REPRESENTATION, Milan, Italy, 13–15 September 2018; pp. 183–186.