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Use of UAVs for Technical Inspection of Buildings within the BRAIN Massive Inspection Platform

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Abstract. Unmanned Aerial Vehicles (UAVs) are becoming more and more popular for use in a various sectors of the economy. The paper presents the results of experiments using a UAV, equipped with a high resolution digital camera, for a visual assessment of technical condition of a building with connection to a big project implemented in Barcelona that required visual data about buildings and their changes with time. Authors try to find out possibilities for the usefulness of digital images obtained from the UAV deck in concrete examples and figure out if they may be complementary to traditional ways used so far in a project called Building Research Analysis and Information Network, which is a platform for analysis to allow strategic decision-making for the maintenance and the sustainability of building stock.

1. Introduction

Recently, BRAIN (Building Research Analysis and Information Network) has been introduced by Serrat et al. (2017) [1] as a platform for the predictive analysis of the urban canyon. The methodology was initially introduced by Serrat and Gibert (2011) [2] and lately developed in [3]. BRAIN proposes, in a collaborative network of urban laboratories, a follow-up across time of the technical condition of the facades in a building stock. Supported by a GIS platform and a survival analysis-based methodology, BRAIN aims to infer on the time to the occurrence of potential failures or lesions in the existing facades. After modelling the time-to-event with the statistically significant variables, the predictive system allows strategic decision-making for the maintenance and the sustainability of the building stock. One of the most relevant issues in the methodology is the data collection procedure. Conventional inspections are primarily based on visual research methods. However, the data collection must be as exhaustive and accurate as possible, in order to minimize the variability among inspectors. As well, a massive and periodic inspection should be efficient in terms of data quality versus time and cost resources.



Also in recent years, a lot of research has been developed exploring the use of digital images acquired through Unmanned Aerial Vehicles (UAVs) monitoring the technical condition of real estate and inventories of technical infrastructure. Within this perspective, Banaszek et al. (2017) [4] have proved the new opportunities that the use of UAVs offers in the area of technical inspection of buildings and constructions. In the civil engineering framework, large structures such as large-scale structures, bridges, chimneys, towers, dams, industrial power plants, power lines are often difficult to access for detailed technical inspection. New UAV data acquisition technologies offer new opportunities in this field. The data acquisition process is the most time-consuming, technically complex and therefore the most costly part of the audit [5]. UAV case studies to monitor the technical condition of objects of different sizes (residential building, dam, retaining wall at the runway) have shown that high resolution image quality enables visual identification of cracks of 0.3 mm at approx. 10 m from the recorded surface [6].

In this paper authors conduct a study by implementing the use of UAVs in the data collection within the BRAIN framework. The main objective of the contribution is the preliminary approach to determine the conditions of use, and to evaluate the benefits, as well as disadvantages, of this high performance technology as a complement or alternative to the traditional method, which is based on visual inspections supported by high resolution digital camera images, for the failures diagnosis of facades. So, the paper presents and discusses the results of experiments using UAV, equipped with a high-resolution digital camera, for a visual assessment of the technical condition of the facades.

The paper is organized as follows. In Section 2 the BRAIN methodology will be introduced, in particular details on the inspection procedure will be given. Characteristics of the sample under study and the corresponding flights will be described in Section 3. Results and discussion will compose Section 4. The paper ends with a summary of the main conclusions.

2. BRAIN methodology

The BRAIN predictive system is integrated by four components. In short, a) the collaborative approach in order to joint and analyze the information from the nodes in the network of urban labs, b) the inspection methodology to be applied in each urban lab, c) the survival analysis methodology as a statistical technique for the durability and modeling estimation and, d) the GIS platform as a tool for managing the information and the analyses. Details of these components can be found in [3]. In this Section we will focus on the two first ingredients.

2.1. A population-based and collaborative perspective

The methodology focuses on a massive prospecting campaign of the facades at a multiscale level. Indeed, it concentrates on the concept of the urban laboratory that collects the envelope of the buildings and constitutes the urban front. Gibert (2016) [3] defines the urban canyon as the U-shape location where the facades are exposed. In the urban canyon the ageing of the building stock population takes place. Territorial and environmental covariates occur and determine the facades durability over time. Figure 1 illustrates the urban laboratory and the urban canyon.

The project, in a networking manner, was born in order to be applied to any city in the world. The net has a neuronal analysis centre, the Collaboratory, as a coordination unit, able to store and analyze the information from the cells in order to test for similarities and differences across the participants (cities, i.e. urban labs). The right-hand part of the figure 1 illustrates the network. The main goal is joint efforts towards the predictive knowledge of the deterioration of the urban fronts and to facilitate the design of common standards and protocols of follow-up and intervention strategy.

2.2. Inspection methodology

Gibert et al (2014) [7] designed the inspection protocol based on a list of requirements in order to apply a population-based approach. The final protocol comes from a weighted criterium that combines issues like identifiability of the facades, classification of the facades, methodological issues themselves, resources needed, data collection, and analytical skills for the decision-making.

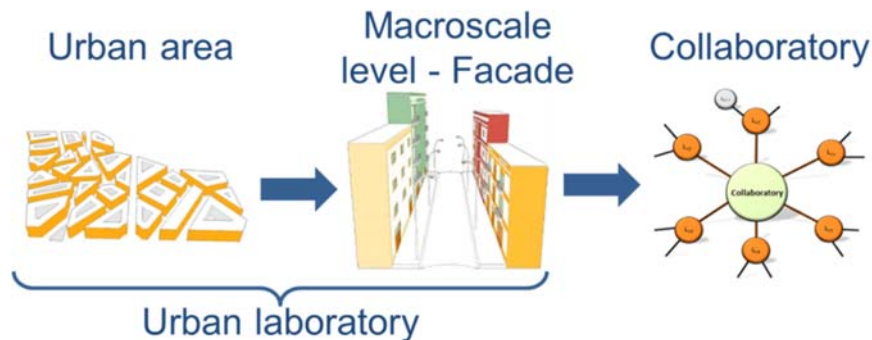


Figure 1. Urban laboratory network and Collaboratory for the BRAIN project

The protocol includes an inspection document that consists of two parts. Part a) allows the collection of field data, cartographic data, cadastral data as well as plot/building/facade data and architectural characteristics. Part b) covers the collecting of existing elements and materials and the state of any damage at the time of inspection. Figure 2 shows part b) of the inspection document in detail.

The visual inspection starts from an inspection system that structures the facade in different configurative possibilities, ergo different morphologies: Flat facades, facades with balconies, facades with tribunes, and facades with balconies and tribunes. In figure 2 it can be seen that each of these parts is analyzed independently within the whole of the facade and its durability is assessed based on a subdivision thereof, as well as its construction materials, injuries, extent and severity based on the perception of the technical inspector.

The methodology is designed to visualize and prospect the facades from the public road with a vision of macro-scale analysis. However, in practice, when considering raised parts in the front of the façade, some elements or states are hidden from their possible detection or there are difficulties to determine with accuracy the severity derived from the injury. This inconvenience motivates the research that we are conducting in order to improve the methodology.

3. Design of the experiment

In order to explore the emerging possibilities derived from capturing the information on the technical condition of the facades through UAV devices, we conducted the following experiment. In this preliminary approach, a) we selected a reduced sample of facades, b) we programmed and executed the flights for the data collection, c) we managed the digital information and, finally, d) we fulfilled the datasheet in figure 2, in the Collaboratory. After comparing traditional visual inspections procedure with UAV-based procedure, final results and discussion were derived. Details are given in the next subsections.

3.1. Facades under inspection

A sample of six facades was selected in Poland, located in Warsaw (4 units) and Olsztyn (2 units). Facades were identified as units 1 to 6, respectively. The sample was chosen based on criteria of morphology and deterioration level. In figure 3 general views and characteristics of the sample under study are shown.

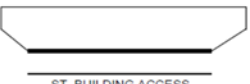
FACADE CHARACTERISTICS			COATING			CON			DIS			MORPHOLOGY			FB			FT			OT					
ADDRESS	Nº	FAC. No	T			C			N			P			D			M			R			S		
			P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G
MAIN BODY																										
WALL-ZB																										
WALL-ZM																										
HOLES																										
LINTEL-ZB																										
JAMB-ZB																										
LINTEL-ZM																										
JAMB-ZM																										
PARAPETS																										
COATING																										
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TILING-ZB																										
TILING-ZM																										
CONTINUOUS																										
PLASTERED MORTAR																										
STUCCO WORK																										
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WALL-1																										
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TILING																										
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EDGES																										
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LEDGES																										
EAVES																										
DAVITS																										
OTHERS																										
 ST. BUILDING ACCESS			TYPE OF DAMAGE						EXTENT			SEVERITY														
			T DETACHMENT			D DEFORMATION			P PUNTUAL			1 SYMPTOM			5 VERY SEVERE											
			C CRACK			M MAT. DEGRAD.			L LOCAL			2 MILD			6 EXTREME											
			N DEBONDING			R CORROSION			G GENERAL			3 MODERATE														
			P SPALLING			S MOISTURE						4 SEVERE														

Figure 2. Inspection sheet for the failures data

Unit 1 (balconies, slightly damaged)



Unit 2 (balconies, heavy damaged)



Unit 3 (flat, no damaged)



Unit 4 (balconies and tribunes, medium damaged)



Unit 5 (flat, heavy damaged)



Unit 6 (flat, slightly damaged)

**Figure 3.** General views of the facades in the sample. In parentheses (morphology, deterioration level)

3.2. Technical details of the UAV

The experiment uses the DJI Inspire One lightweight quadcopter with the following specifications: weight: 2,935g, vertical GPS accuracy: 0.5 m (accuracy determination), horizontal GPS accuracy: 2.5 m (accuracy of X, Y coordinates), climb speed: 5 m/s, max. drop speed: 4 m/s, max. cruising speed: 22 m/s (ATTI mode, no wind), max. flight height: 4,500 m ASL (Above Sea Level), max. wind force: 10 m/s, flight time: 18 minutes, operating temperature: -10°C to 40°C, size: 438x451x301 mm.

To obtain digital images the UAV was equipped with a Digital camera (RGB sensor) with the following specifications: 12 Mpix resolution (4,000x3,000 pixels), physical size 6.170 mm x 4.628 mm, focal length: 3.55 mm.

3.3. Description of the flights

Using UAV for commercial and scientific purposes requires in Poland a qualification certificate of UAVO unmanned aircraft operator. This requires Art. 95 of the Law of July 3, 2002, aviation law, and the detailed rules for obtaining the certificate are contained in the Regulation of the Minister of Transport, Construction and Maritime Economy of 3 June 2013 on certificates of qualification. Basic Visual Sight of Sight operation (VLOS) deals with the operation of UAV sightings. It is received by the operator after the completion of theoretical and practical training and passes the state examination, which is conducted by an examiner appointed by the Polish Civil Aviation Office.

Three different flights were planned. In particular, surface raids were designed and executed using Map Pilot software, an iOS application that enables the design of an automated UAV flight. Specific flights conditions per each one of the days are displayed in table 1. In all the cases, conditions were good enough for a successful data collection.

Table 1. Flights conditions for each flying day.

Date [dd/mm/yyyy]	Temperature [°C]	Wind [km/h]	Humidity [%]	Precipitation	Sun
29/07/2016	22	12	63	No	Sunny
24/10/2016	10	9	77	Drizzle	Moderate clouds
10/03/2018	11	8	47	No	Sunny

Table 2 presents the window time for the flight as well as the volume of data and number of images collected, per each one of the facades. Duration times range from 5 minutes to 29 minutes and the size of the files is 5 Mb per image, approximately.

Table 2. Identification of the facades, flights times and information collected.

Facade ID	Date [dd/mm/yyyy]	Time of the flight [hh:mm]	Duration of the flight [min]	Amount of data obtained [Gb]	Number of images
1	10/03/2018	10:36 - 11:05	29	5.66	1060
2	10/03/2018	11:20 - 11:39	19	4.68	886
3	10/03/2018	12:30 - 12:40	10	2.07	375
4	10/03/2018	12:52 - 13:05	13	2.49	461
5	29/07/2016	15:09 - 15:14	5	0.17	34
6	24/10/2016	15:59 - 16:11	12	0.63	126

4. Results and discussion

After the flights the images were processed and analyzed, facade by facade, by the technical inspector in the Collaboratory. Figure 4 displays a set of selected images that give support to the main contributions that can be derived from the analysis. It is important to notice that, in essence, all the results are positive. Main advantages and possibilities are listed in what follows.

- UAV strengths include high mobility in data acquisition and the ability to fly at different heights
- To observe any area of the facade with sufficiently precise approaches to detect any type of existing injury. In addition, the results of the images are sufficiently explicit as to enable an expert to identify the existing architectural elements and their construction techniques (figure 4).



Figure 4. Selected images to illustrate different views of the facades and several injuries, extents and severities.

- Sweeping of the camera from top to bottom, which cannot be replicated by the inspector from the public way, allows making visible parts and elements of the façade which were not visible till now (figures 4.1, 4.2, 4.3 and 4.12).
- To zoom the images, when it is necessary, allows the inspector to detect the extent of the injuries (figures 4.4, 4.5 and 4.6).
- To accurately diagnose the injury and its severity. (cracks and wear of material, figure 4.7; interim interventions, corrosion of railing and type of wall anchor, figure 4.8; breaks of work elements fastened by downpipes, figure 4.9; detachment with lack of lateral adhesions, figure 4.10; fissure with movement and detail of detachment of plaster, figure 4.11 and eave break with channel detail with tile joint and break state, figure 4.12).
- The amount of information on the technical condition of the facade that it is collected, allows the inspector to perform accurate posterior measurements and analyses. This is a really positive extra values of the UAV technology. For instance, after rectification and scaling of the images orthophotos can be obtained.

Another advantage, not minor, consists in the possibility in future inspections of contrasting states of evolutionary degradation of the lesions or their transformation, with a perfect identification within the facade element. Even in the cases of rehabilitation of the facades, having their historical of previous injuries can help to understand how the durability behaves and why, according to former or new parameters.

From the experiment it can be also derived some learnings that could become limitations in some manner.

- We cannot ignore the existence of very strict regulations when carrying out these types of flights within a consolidated urban environment. Fortunately, new laws are progressively regulating the use of UAVs, in a more open perspective. Anyway, this circumstance would have to be considered in urban laboratories that have these restrictions.
- The capture of images through UAV technology generates a very large amount of accurate information, in this first approach to the state of the facade. One important requirement in the BRAIN population-based methodology is the efficiency in terms of time and costs. Based on this, the analyst is forced to become familiar with files that range from the totality of the facade to each of the parts in which the facade is subdivided. This fact, far from being a problem, suggests that a structuring of information is needed, as well as, that an a priori technical flight plan is recommended.
- When analysing time needed to fill in the form in figure 2, we need to take into account three different periods: pre-flight, in-flight and post-flight. In other terms, the preparation of the plan for the flight, the collection of the images and the analysis of the information, respectively. Although the total time is greater than the one needed for a traditional inspection, the quality and quantity of the information that it is collected justifies the UAV methodology.

5. Conclusions

Based on the conducted experiment it can be stated that the use of UAVs for technical inspections of the facades in a building stock is an interesting alternative to the traditional visual inspections from the public way. The use of UAV provides new opportunities in the area of technical inspections due to the detail and accuracy of the data, low operating costs and fast data acquisition time. Despite it would be necessary to complement the experiment with a more detailed cost and time analyses, the main advantages of using UAV have been proved.

The most positive contribution of UAV data acquisition to the BRAIN platform would be the reduction of the variability, from two different perspectives. On one hand, by reducing the differences between inspectors in the injuries identification and the extents and severities diagnosis. On the other hand, by minimizing the within inspector variability due to the best information's quality. This is one

important issue in order to obtain more accurate confidence intervals in the prediction of the durability.

Finally, it is relevant to notice that the quantitative analysis of the technical condition of the facade via UAV hints a potential underestimation of the real condition of the facade when using traditional visual inspections. In order to confirm this hypothesis new research needs to be developed.

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