KOSZALIN UNIVERSITY OF TECHNOLOGY

RESEARCH AND MODELLING IN CIVIL ENGINEERING 2018

Edited by
Jacek Katzer, Krzysztof Cichocki and Jacek Domski

KOSZALIN 2018

MONOGRAPH NO 355
FACULTY OF CIVIL ENGINEERING,
ENVIRONMENTAL AND GEODETIC SCIENCES

ISSN 0239-7129
ISBN 978-83-7365-502-7

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KOSZALIN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE
75-620 Koszalin, Racławicka 15-17, Poland

Koszalin 2018, 1st edition, publisher's sheet 13,42, circulation 120 copies
Printing: INTRO-DRUK, Koszalin, Poland

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2. Quantitative comparison between visual and UAV-based inspections for the assessment of the technical condition of building facades

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Abstract: In this chapter authors conduct a case study analysis in order to evaluate the potential benefits of using Unmanned Aerial Vehicles (UVAs) for the data collection involved in the failures diagnosis of facades. A quantitative approach is performed by testing for statistically significative differences between the proposed methodology and traditional visual inspections. Results allow to state that a highly significative global improvement for the data collection exists.

Keywords: UAV, building façade, quantitative comparison

2.1. Introduction

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) 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 (Eschmann *et al*, 2012). 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 (Hallermann et al., 2015).

Independently, BRAIN (Building Research Analysis and Information Network) has been introduced by Serrat *et al*. (2017a) as a platform for the predictive analysis of the technical condition of the urban canyon. The methodology was initially introduced by Serrat and Gibert (2011) and lately developed in Gibert (2016). 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 ocurrence of potential failures or lesions in the existing facades. After modeling 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 (Serrat *et al.*, 2017b). 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.

In this Chapter authors conduct a quantitative analysis for checking the potential benefits of implementing the use of UAVs in the data collection within the BRAIN framework. The main aim of the contribution in this preliminary approach is to quantitatively assess the improvement with respect to visual inspections concerning the estimation of the technical condition of the facades by using this high graphic capture technology.

The Chapter presents and discusses the quantitative results of an experiment using UAV, equipped with a high-resolution digital camera (Serrat *et al.*, 2018a), for the failure diagnosis of facades in comparison to the visual assessment of the technical condition of the facades.

The Chapter is organized as follows. In Section 2.2 details on the BRAIN methodology and the previous UAV experiment and analysis will be introduced. Methodology used for the quantitative analysis will be described in Section 2.3. Results and discussion will compose Section 2.4. The Chapter ends with a summary of the main conclusions and a description of the ongoing research.

2.2. Previous work

We introduce in this Section the fundamentals of the BRAIN inspection methodology as well as the preliminary experiment and contributions related with the use of UAVs for the technical condition assessment.

2.2.1. BRAIN methodology

The BRAIN predictive system (Serrat *et al.*, 2017a) 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. BRAIN protocol is integrated by four components. In short, a) a collaborative approach in order to joint and analyze the information coming from the nodes in the network of urban labs, b) an inspection methodology to be applied in each urban lab, c) a survival analysis methodology as a statistical technique for the durability and modeling estimation, and d) a GIS platform as a tool for managing the information and the analyses. Details of these components can be found in Gibert (2016).

The inspection protocol was designed in Gibert, Serrat and Casas (2014). It is based on a list of requirements in order to apply a population-based approach, that is to be applied in a massive manner in big cities. The final protocol was inspired in a previous datasheet developed by the Laboratory of Building (LABEDI) at the Barcelona School of Building Construction. That former datasheet evolved towards 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 and the methodology aims to be efficient in each of the requirements.

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. Fig. 2.1 shows part b) of the inspection document in detail. According to this second sheet the types of injuries analyzed in the inspected built environment are as follows:

- Mechanical injuries that appear from external or internal forces, having an effect on the mechanical integrity of the construction elements: detachment, crack, debonding, spalling and deformation.
- Chemical injuries as a result of chemical reactions between the materials that make up the construction elements and the atmospheric factors or other polluting products contained in the surrounding environment: material degradation and corrosion.
- Physical injuries caused by a process related to the physical laws, affecting the physical characteristics of the constructive elements and materials: moisture, as well as material degradation.

2.2.1. Preliminary UAV experiment and contributions

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 preliminary experiment.

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 Fig. 2.2 general views and characteristics of the sample under study are shown.

The experiment used 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. More details on the description of the flights can be found in Serrat *et al*. (2018a).

After the flights the images were processed and analyzed, facade by facade, by the technical inspector and the main advantages and possibilities were: a) UAV strengths include high mobility in data acquisition and the ability to fly at different heights, b) 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), c) sweeping of the camera from top to bottom allows making visible parts and elements of the facade which were not visible at that moment, d) zooming the images, when it is necessary, allows the inspector to detect the extent of the injuries, e) to accurately diagnose the injury and its severity, and f) the amount of information on the technical condition of the facade allows the inspector to perform accurate posterior measurements and analyses (Serrat *et al.*, 2018a).

Based on the conducted experiment authors stated that the use of UAVs for technical inspections of the facades in a building stock was an interesting alternative to the traditional visual inspections from the public way. The use of UAV provided 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.

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	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G	P	L	G
DISCONTINUOUS																								
TILING-ZB																								
TILING-ZM																								
CONTINUOUS																								
PLASTERED MORTAR																								
STUCCO WORK																								
SCRATCH WORK																								
FINISHING																								
DECK RAILING																								
WALL-1																								
WALL-2																								
TILING																								
PLASTERED MORTAR																								
SERIF																								

PROJECTING BODIES	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
BALCONIES																								
SLAB-1																								
SLAB-2																								
EDGES																								
UNDER BALCONY																								
RAILING																								
WALL-1																								
WALL-2																								
TILING																								
PLASTERED MORTAR																								
SERIF																								
TRIBUNES																								
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UNDER TRIBUNE																								
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WALL-2																								
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STUCCO WORK																								
SCRATCH WORK																								
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LINTELS																								
JAMBS																								
PARAPETS																								
OTHER ELEMENTS																								
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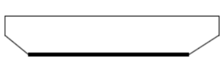

ST. BUILDING ACCESS

TYPE OF DAMAGE			
T	DETACHMENT	D	DEFORMATION
C	CRACK	M	MAT. DEGRAD.
N	DEBONDING	R	CORROSION
P	SPALLING	S	MOISTURE

EXTENT	
P	PUNTUAL
L	LOCAL
G	GENERAL

SEVERITY			
1	SYMPTOM	5	VERY SEVERE
2	MILD	6	EXTREME
3	MODERATE		
4	SEVERE		

Fig. 2.1. Inspection sheet for the failures data in the BRAIN protocol

Fig. 2.2. General views of the facades in the sample. In parentheses (morphology, deterioration level)

Recently, Serrat *et al.* (2018b) conducted a qualitative study in order to analyse the goodness of fit to the fundamental requirements that support the BRAIN inspection methodology. Authors concluded that, based on the data from the abovementioned experiment, traditional inspections are nowdays slightly better scored than the UAV alternative. However, UAV scenario is quickly changing over time and the alternative is quite promising. On the one hand, the advantage in requirements as data quality and analysis are not questionable at all. On the other hand, authors noticed that technological progress will move this UAV resource to a more standard, better well-known and cheaper technology. Within this perspective UAV-based inspections can really improve their compliance with the standards of the requirements for a large-scale inspection protocol.

2.3. Materials and methods

Each of the injuries in Fig. 2.2 is evaluated according to its extent, by means of a visual approach: puntual (P) when less than 25% of the element is injured, local (L) when failures affect between 25% and 50% of the element, and general (G) when injuries exceed 50% of the element. Injuries are also evaluated in terms of severity by assigning, for each of the elements, a numerical value from 0 to 6 according to the severity of the injury observed in the element. This information allows to compute, numerically and graphically, the Weighted Severity Index (WSI) of the injuries as a weighted mean which allows the researcher to obtain a general image of the global condition of the damage in the facade.

If we denote by $\mathcal{E}$ the set of existing elements in a facade, the WSI of the facade is given by the weighted mean of the injury severities, across the elements in $\mathcal{E}$, with weights 1, 2 and 3 for the extent variable, that is

$$WSI = \frac{\sum_{i\in\mathcal{E}}(P_i+2L_i+3G_i)}{18\cdot card(\mathcal{E})}\cdot 100 \quad (2.1)$$

where P_i, L_i and G_i denote the severities with puntual, local and general extent, respectively, being 18 (=3·6) de potential maximum contribution of an injury, and $card(\mathcal{E})$ the cardinal of $\mathcal{E}$, i.e. the number of existing elements. The WSI represents the percentage of damage, in terms of severity and extent, of every facade and it is computed for each of the aforementioned injuries, as well as for the different parts of the facade (body, deck railing, balconies and tribunes).

For each facade, datasheet for the failure condition will filled twice: firstly based on the visual inspection, and secondly based on the pictures obtained from the UAV flights. Let denote by WSI_{Vis} and WSI_{UAV} the WSI values derived from each of the methodologies, respectively.

Based on the previous works and the high graphic quality of the images reported by the UAV methodology, we can assume that estimated percentage of damages in the facades will be higher with this methodology in comparison to the visual one, i.e. $WSI_{UAV} \geq WSI_{Vis}$.

Let denote by Δ the potential improvement in the percentage of failures according to the expression

$$\Delta = WSI_{UAV} - WSI_{Vis}. \tag{2.2}$$

We are interested in the estimation of the expectation of Δ, $\mu = E(\Delta)$. The estimated value of this expectation corresponds to the difference between the respective means, that is

$$\hat{\mu} = \overline{WSI}_{UAV} - \overline{WSI}_{Vis}. \tag{2.3}$$

In order to decide on the significance of this improvement, we will apply a unilateral (right tail) paired t-test to the WSI pairs of data collected per façade. The aim is to test for the existance of statistically significative differences in favor of an alternative hypotesis that is proposing positive improvements. The formulation of the hypothesis test is as follows

$$\begin{cases} H_0: \mu = 0 \\ H_1: \mu > 0 \end{cases} \tag{2.4}$$

and, under normality distribution conditions and controlling by the dependency between the measurements in a façade, the *t*-value statistic follows a t-Student distribution with *n*-1 degrees of freedom, where *n* is the sample size.

2.4. Results and discussion

The results of the twelve hypothesis tests are shown in Table 2.1. Per each of the injuries and each of the parts of the facade, the sample size (*n*), the estimation of the expected improvement ($\hat{\mu}$), the standard error of the mean (s.e.), the p-value and the significance of the test are reported.

From the results in Table 2.1 the following remarks can be derived:

a) In the case of the deformation injury test could not be applied because in every unit (facade) values for extent and severity of the injuries both for the UAV-based and visual-based inspection coincide.

b) For crack, spalling, material degradation, and moisture injuries differences are almost significative. This fact suggests that under a larger sample size, the statistical power of the test would be higher and significative differences could be found.

c) For the WSI computations for the body of the facade, differences are really significative. This global benefit of the UAV methodology supports the evidences in favor of using this technology for the data collection.

Table 2.1. Results of the hypothesis test per each of the injuries (8) and each part of the facade (4). (n: sample size, $\hat{\mu}$: estimation of the expected improvement, s.e.: standard error of the mean, n.a.: not available, -: $p \geq 0.05$ non significative, *: $p < 0.05$, significative, **: $p < 0.01$, very significative, ***: $p < 0.001$, highly significative)

	n	$\hat{\mu}$	s.e.	p-value	Significance
Injury					
Detachmet	6	0.133	0.102	0.124	-
Crack	6	1.067	0.669	0.086	-
Debonding	6	0.133	0.133	0.182	-
Spalling	6	0.750	0.379	0.052	-
Deformation	6	0.000	0.000	n.a.	n.a.
Material Degradation	6	0.783	0.408	0.056	-
Corrosion	6	0.417	0.288	0.104	-
Moisture	6	3.470	1.960	0.069	-
Part of the facade					
Body	6	0.617	0.130	0.003	**
Deck Railing	3	0.833	0.463	0.107	-
Balconies	3	0.733	0.433	0.116	-
Tribunes	3	0.450	0.071	0.035	*

d) For the case of assessing the technical condition of tribunes, UAV-based strategy also improve significatively the estimation of the percentage of damage in this part of the facade.

2.5. Conclusions and ongoing research

Concerning the comparative analysis aimed to assess the improvement of using UAV inspections versus visual ones in measuring the technical condition of facades, the experiment and posterior analyses allows to draw the following conclusions:

- Potential quantitative benefits of the UAV-based methodology have been shown.
- Despite at the injury level there are only some cases in which differences are significative, at the part-of-the-facade level there is a highly significative global improvement.
- The possibility of collecting images at different heights drives to a significative improved diagnosis at the level of tribunes.

After these preliminaries studies, authors' ongoing research on the topic addresses, in an holistic manner, issues like a) to review the list and weights of the general and specific requirements for the BRAIN protocol of inpections, in order to take into account the use of high graphic capture technologies, b) to extend the source of images management to ortophoto, photogrammetry, 3D point-cloud, termographic camera as a potential alternative or complement to the traditional inspection methodology, c) to incorporate the urban canyon perspective in the approach of the massive inspection methodology instead of the isolated building case considered in this experiment, d) to increase the sample size of the study for a better sampling of variables like morphology and level of damage, and e) to explore adaptative and smart flying plans in order to get a more efficient data collection.

Acknowledgements

This research has been partially supported by grants MTM2015-64465-C2-1-R (MINECO/FEDER) from the Ministerio de Economía y Competitividad (Spain) and 2017 SGR 622 from the Departament d'Economia i Coneixement de la Generalitat de Catalunya. Authors are grateful to the Laboratory of Photogrammetry and Remote Sensing (LFiT) Dron House S.A., Warsaw (Poland) its contribution in the technical part of using UAV technologies, as well as, to members of the IEMAE, LABEDI and GRASS-GRBIO groups their valuable comments and suggestions in the development of the work.

References

Banaszek, A. *et al.* (2017) 'Possibilities of Use of UAVS for Technical Inspection of Buildings and Constructions', *IOP Conference Series: Earth and Environment Science*, 95, 032001, pp. 1–6.

Eschmann, C. *et al.* (2012) 'Unmanned Aircraft Systems for Remote Building Inspection and Monitoring', in *Proceedings of the 6th European Workshop on Structural Health Monitoring*, Th.2.B.1, pp. 1–8.

Gibert, V. (2016) 'A multiscale predictive system for the degradation of the built urban front, *PhD Thesis, Universitat Politècnica de Catalunya-BarcelonaTECH*, Barcelona, Spain, (in Spanish).

Gibert, V., Serrat, C. and Casas, J.R. (2014) 'Determination of criteria for the exploration and for obtaining indicators in evolutional analysis of degradation in urban facades', in *Proceedings of the 13th International Conference on Durability of Building Materials and Components*, Sao Paulo, Brasil, pp. 656–663.

Hallermann, N. *et al.* (2015) 'Unmanned Aerial Systems (UAS) – Case Studies of Vision Based Monitoring of Ageing Structures', in *Proceedings of the International Symposium Non-Destructive Testing in Civil Engineering*

(NDT-CE), Berlin, Germany.

Serrat, C. *et al.* (2017a) 'BRAIN: Building Research Analysis and Information Network', in *Proceedings of the XIV International Conference on Durability of Building Materials and Components*, Ghent, Belgium, 325, pp. 1–11.

Serrat, C. *et al.* (2017b) 'On the selection of significant variables in a model for the deteriorating process of facades', *IOP Conference Series: Materials Science and Engineering*, 251, 012071, pp. 1–8.

Serrat, C. *et al.* (2018a) 'Use of UAVs for Technical Inspection of Buildings Within the BRAIN Massive Inspection Platform', *IOP Conference Series: Materials Science and Engineering*, to be published.

Serrat, C. *et al.* (2018b) 'Exploring Conditions and Usefulness of UAVs in the BRAIN Massive Inspections Protocol', Submitted to *Open Engineering*.

Serrat, C. and Gibert, V. (2011) 'Survival analysis methodology for service live prediction and building maintenance', in *Proceedings of the 12th International Conference on Durability of Building Materials and Components*, Porto, Portugal, vol. II, pp. 599–606.