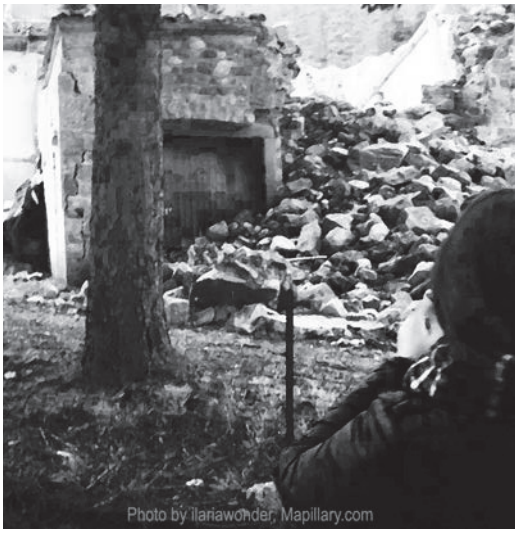
Photo by ilariawonder, Mapillary.com

OPPORTUNITIES FOR THE USE OF COLLABORATIVE 3D MAPPING IN POST DISASTER SITUATIONS

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How to cite item in APA format:
Pezzica, C., Cutini, V., & Bleil de Souza, C. (2018). Opportunities for the use of collaborative 3D mapping in post-disaster situations.
In A. Leone & C. Gargiulo (Eds.), *Environmental and territorial modelling for planning and design*.
(pp.475-482). Naples: FedOAPress. ISBN: 978-88-6887-048-5, doi: 10.6093/978-88-6887-048-5

ABSTRACT

The rising incidence of disasters, the call for community participation in planning and the widespread diffusion of technology, have recently posed a number of new challenges and opportunities in mapping for disaster response and recovery. Expectations are generally higher than in past times, urban settlements tend to become increasingly complex, and collaborative platforms and apps have started to appear as a bottom-up response to the issue of data accessibility. To promptly assess and monitor post-disaster situations and plan for contexts susceptible to worse damage in the event of aftershocks, many research projects have recently tackled the issue of the quick delivery of cartographies though fit-for-purpose automated mapping procedures. Rapid mapping seems, in most cases, to be bind to the use of satellite imagery. Indubitably, satellite data are an invaluable source of broad scale information along the entire disaster management cycle. However, weather conditions may prevent the images acquisition; damage of the buildings facades cannot be directly perceived; if the elements to map are too small problems of data reliability and accuracy arise; 3D information are limited and update frequency might be insufficient. Given the demand for the continuous enhancement of current mapping products, this paper aims at highlighting novel occasions for the complementary use of photogrammetry as a means to collaboratively enrich remotely sensed information through the processing of street-level imagery collected by people, using smartphones. This may help the planner when, under certain circumstances, spatial data were either unavailable, too poor or excessively delayed.

KEYWORDS

3D Collaborative Mapping; Post-Disaster Planning; Crowdsourced Data Collection; Photogrammetry; Open Data

1 INTRODUCTION

During all phases of Disaster Management (DM), from disaster prevention up to post-disaster reconstruction, mapping and spatial data services are essential to assess the needs of people and inform planning decisions. However, the way and the scope for the use of such data varies a lot according to the demands of the different phases in the DM cycle. Before a disaster strikes, the data are used to identify vulnerabilities in the urban configuration and infrastructure; propose solutions to mitigate potential damages; develop operational plans and project scenarios. In the aftermath of a disaster, they support real-time situation and damage assessment (size of the impacted area, intensity of damage, location of victims, access to infrastructure etc.) and later recovery planning, monitoring and change detection, which becomes fundamental where further losses in the event of aftershocks, are expected. In such emergency contexts, it is critical to collect the relevant geo-spatial data quickly. However, information also need to be of the highest possible quality and strictly up-to-date. Therefore, research projects have tackled the issue of their prompt delivery (Baltsavias et al., 2013; Hein et al., 2017) and serious concerns are emerging with regards to efficiency in data acquisition and processing (Toschi et al., 2017). To date, research on rapid mapping procedures seems mainly bind to the elaboration of space and airborne imagery as they remain the main source of broad to medium scale information. High-resolution satellite images currently represent the main information source for rescuers and planners as they come with a rare combination of acceptable spatial resolution (from 30m up to as little as 0.5m), fair update frequency (a few days), and source reliability. Despite these unique capacities, the use of such imagery comes with some limitations. Among others, the Copernicus Emergency Management Service (Copernicus Observer, 2017) highlights three issues: weather-related factors such as cloudiness and atmospheric haze may prevent its effective usage; damage of the buildings facades cannot be directly perceived; if the elements being examined are too small, issues of accuracy may arise. In an attempt to deal with these issues, in 2016 the Copernicus conducted a pilot study in the areas affected by the Central Italy earthquake and tested the potential of deploying manned and Unmanned Aerial Systems (UAS) for the acquisition of a complementary image dataset in support of emergency management actors. The combination of satellite images with other data sources has been suggested in the literature (Casagli et al., 2017) as a way to provide higher spatial detail, better time resolution and mitigate weather–related problems. Ground surveys and visual inspections are still widely used by engineers to inform citizens about whether their homes are safe or by conservation architects when cultural heritage is concerned. In some instances, planners require ground-level information to select the locations for emergency housing camps or to study new mobility routes, but it's when they are required to work at the micro scale (e.g. to design small temporary housing settlements) that they become crucial. Besides, disasters may hit relatively isolated areas in poorly connected territories, previously mapped only at a regional scale as in the Italian case, where the aftershocks had unleashed waves of destruction over a very large rural area, dotted with remote villages, in many cases accessible via only one or two roads due to the complicated topography of the Apennine mountains.

This paper aims to highlight novel opportunities for the complementary use of photogrammetry as a tool to undergo street-level surveys both at the building and at the urban scale. Point clouds can be used as part of a Scan-to-BIM process whereas 3D models from photogrammetry to retrieve updated measurements. The proposed method relies heavily on crowdsourcing as a way to collaboratively collect image sequences captured by people on site. A similar collaborative approach to the use of photogrammetry has recently been tested by Poiesi et al. (2017) giving promising results. The authors have tested the effectiveness of the proposed technique to work in post-disaster situations on an image database built by the local population in Central Italy. The results include the 3D models of a portion of Norcia's historic urban walls and of a construction site in Arquata del Tronto. The work is meant to add to the current debate on the integration of alternative data sources for rapid mapping purposes by favouring the perspective of the architect\engineer\planner called to work at the micro-scale, where accurate 3D information are needed. Strengths and limitations for the use of the proposed method are discussed at the end.

2 METHODOLOGY

In order to derive 3D information from a series of 2D image sequences we made use of a photogrammetric range imaging technique known as Structure from Motion (SfM). SfM is a low-cost and user-friendly technique for obtaining high-resolution models at a range of scales; the main advantage being that SfM enables to simultaneously calculate the camera position while solving the scene geometry in an automated, reliable and relatively quick, way (Westoby et al., 2012). This technique can be applied to image datasets collected by common people moving in a space by using just a smartphone or an action camera. The final result is a 3D reconstruction of the captured scene, which maintains the proportions between the objects. However, as the reconstruction is scale-invariant, the knowledge of at least one measure is required to scale the 3D model to its actual dimensions.

This method (Figure 1) enables the derivation of a scaled texturized 3D model from 2D pictures by applying SfM processing techniques to image sequences available online through the following five steps:

- image crowdsourcing\data gathering;
- image grouping, selection and pre-processing;
- image alignment (bundle adjustment) and dense 3d point cloud generation;
- 3D point cloud scaling;
- mesh construction (3D model).

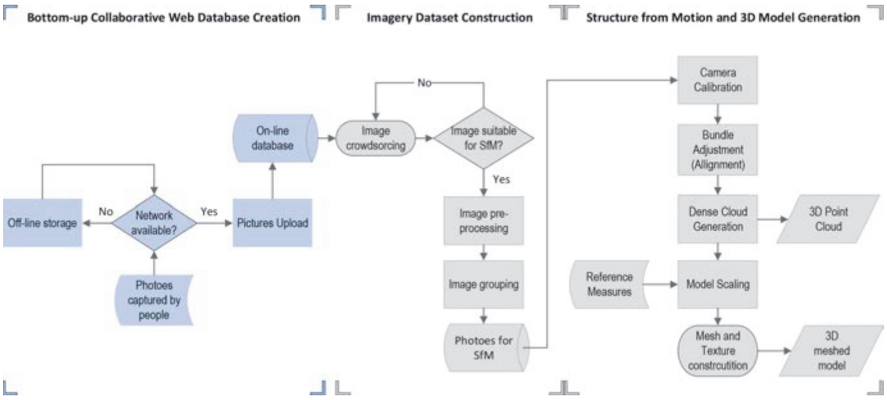

Fig. 1 Flow chart of the collaborative digital workflow; shapes follow the convention of ©Microsoft Visio

3 DETAILED METHODS AND THE PILOT STUDY

3.1 IMAGE CROWDSOURCING

A good resource for data gathering is Mapillary, which is an open[1] collaborative platform for extracting mapping data in scale using Computer Vision. Mapillary's images are geotagged (have associated GPS information), so they can be visualised in ordered sequences on a web map. Also, they are clustered in time-referenced groups uploaded by different contributors, which enables a fast automatic sequence download. Photos do not have associated metadata (EXIF files), but there is an option to retrieve them if required by the SfM. In the pilot study the images have been entirely collected from Mapillary as the administrator of *Terremoto Centro Italia*[2] (Terremoto Centro Italia, 2016) invited the earthquake-affected people to upload their photos on the platform; stressing the need for post-disaster storytelling and visual descriptions of the many small villages and routes usually rather ignored or underexplored by global mapping services. Additionally, the post highlighted possibilities for users to computationally extract useful information from the images that can be then mapped into OpenStreetMap (OSM) or used for change detection and monitoring. It also mentions the possibility to derive 3D reconstructions from photos by means of a tool called OpenSfM (Gargallo, 2016).

3.2 IMAGE SELECTION, PRE-PROCESSING AND GROUPING

SfM's operative capacity depends on a redundant bundle adjustment based on matching features in many overlapping, offset images. This requires the images to have enough overlap (~20%) and to contain stereo-pairs with sufficient image sharpness (quality ≥ 0,5 in ©Photoscan). A good image pre-selection prevents to process groups that would either fail alignment or be likely to generate inaccuracies in the final model. It may also be necessary to check images' exposure and act upon it beforehand, in case they present abrupt lighting variations. Whenever pictures are poorly exposed, it is recommended to shift their histogram accordingly.

In the pilot study, these tasks have been performed in a supervised way, but there may be scope for this to be automated. In the end, the authors selected and prepared two groups of images: 21 photos portraying severe damages in Norcia's historic walls; and 68 pictures of a temporary housing site in Arquata del Tronto.

3.3 IMAGE ALIGNMENT AND 3D POINT CLOUD GENERATION – SFM

Before proceeding with the bundle adjustment the SfM program requires to calibrate the cameras as distortions can affect the results. This involves identifying the types of lenses used to capture the pictures to be processed. Next, some noisy elements such as cars or people may need to be masked to avoid their processing. After choosing the maximum number of key points (feature points) that ©Photoscan uses to reconstruct the sparse point cloud, images are automatically aligned. Next, it generates the 3D dense cloud,

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[1] LCC BY-SA (Creative Commons Attribution–Share Alike License) grants four freedoms: use and perform the work; study the work and apply the information; redistribute copies; and distribute derivative works. It comes with some key restrictions: to give proper attribution to the author and release derivative works under an identical or similar license, without the possibility of restricting access to the work.

[2] Terremoto Centro Italia is also a collaborative Platform, born as a bottom-up response to allow better community collaboration after the Italian earthquake (Terremoto Centro Italia, n.d.)

whose pre-set accuracy (from low to ultra-high) must be chosen according to the actual needs of the professional who is intentioned to use the final model, as it affects processing time.

In the pilot study, a fisheye calibration was used for Norcia, where pictures had been captured with an action camera. In Arquata's sequence the calibration was kept on frame, as the photos were made with standard lenses. Because Norcia's historic walls were well texturized, less tie points were used to align the images. For Arquata del Tronto this was not the case and more points and a mild depth filtering setting were required to reconstruct the scene in 3D. The adopted parameters are reported in table 1.

VARIABLES	NORCIA	ARQUATA DEL TRONTO
Number of pictures	21	68
Images resolution (pixels)	20148 x 1536	2048 x 1152
Mapillary user and date of upload	Kymolos _ 13\12\2016	Chiccap _ 29\04\2016
Camera Calibration	Fisheye	Frame
Key and Tie point limit	40000, 2000	0, 0
Bundle Adjustment (min)	0,91	19,710
Filtering type	Aggressive	Mild
Dense Cloud Accuracy	Ultra High	Ultra High
Number of points	4.712.160	2.335.922
Dense Cloud generation (min)	3,24	46,045

Tab. 1 SfM processing times and settings for the two case studies

3.4 3D MODEL SCALING

The 3D point cloud generated by the SfM algorithm needs to be scaled appropriately before it can be used to derive plans, sections, elevations, or any other metric information. Scaling requires referencing, which can be done either on the 3D point cloud or on the meshed object. The first option is to prefer when the intention is to create a BIM or HBIM model by using the point cloud as a geometric reference. Opportunities for similar applications at the Urban level are explored in (Courtney et al., 2017).

In this pilot study, we decided to scale the point cloud (Figure 2) as this tends to produce more accurate results. In Norcia's case the OSM cartography was downloaded from the internet and the footprint of a bastion was used as a reference for this task; Arquata's point cloud was scaled in a similar way.

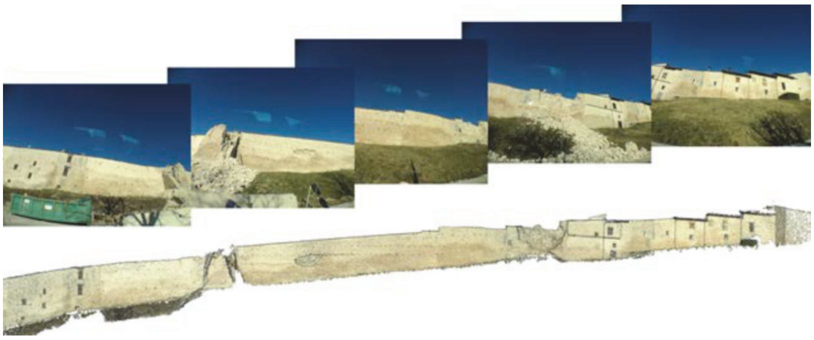

Fig. 2 Frames of Norcia's image sequence and 3D point cloud frontal view

3.5 MESH CONSTRUCTION

The final step is the construction of the texturized 3D model, which can be a reference for problem visualisation and project communication. ©Photoscan has an internal tool to perform this task, which allows to choose between a geometry generation optimised either for terrain or 3D object modelling. However, it may still be necessary to adjust geometry topological errors or to decrease the mesh complexity. Figure 3 provides an illustration of Arquata's 3D model before post-processing.

To sum up, table 2 shows how long it took to complete each of the 5 steps described this section for the pilot study. The time for completion was relatively short, in the order of minutes, with a maximum total of 90 minutes[3].

TASK-SPECIFIC DURATION (min)	NORCIA	ARQUATA DEL TRONTO
Step 1 : image download (crowdsourcing)	~1	~2
Step 2 : image selection, pre-processing and grouping	~5	~10
Step 3 : structure from motion	4,15	65,76
Step 4 : 3D model scaling	~ 8	~ 10
Step 5 : mesh construction	5,82	2,93
Total processing time	~24	~90

Tab. 2 Processing time breakdown

4 DISCUSSION

Because nearly all information that is possible to access remotely in a short time can be valuable to decision-makers, SfM holds potential for offering a worthy additional support to the other surveying techniques used in disaster management. The proposed collaborative digital workflow represents an opportunity to complement data collected by satellites with 3D models. However, further studies on rapid "multi-scale" mapping are still required to integrate the use of crowdsourced street-level imagery in an automated workflow.

A clear limitation of the proposed method is that remote communication is likely to be affected in the hours following a disaster by disruptions in the network. However, some rescue teams are equipped with powerful and portable telecommunication systems for the provision of a better group-effort coordination, as for example the Italian Civil Protection body. Alternatively, pictures may be stored locally and uploaded at a later time.

Further limits concern the absence of guidelines for collaborative data generation in post-disaster situations. For instance, many of the datasets downloaded for this study had insufficient overlapping area or image quality and presented objects that did not fully occupy the scene, ultimately causing the impossibility to use many of the images for photogrammetry purposes.

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[3] Hardware of the of the laptop used to run the test. CPU: Intel(R) Core(TM) i7-4712HQ, 2.30GHz. RAM: 15,9 GB. GPU: NVIDIA GeForce GT 750M/PCIe/SSE2.

Fig. 3 Arquata del Tronto case study. From top-down: section of the 3D point cloud; point cloud with aligned photos; meshed model

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Camilla Pezzica, engineer, is a PhD candidate at the University of Pisa. In 2016, she joined the Welsh School of Architecture, Cardiff University as a Research Assistant to work in the Shelf-life project, funded by the Arts and Humanities Research Council (AHRC). Her research embraces both the fields of Town Planning and Architecture and is conducted in collaboration between the University of Pisa and Cardiff University. Her interests are in the integration of new technologies and computational analysis methods for the multidimensional study of the built environment.

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Clarice Bleil de Souza is a Senior Lecturer at the Welsh School of Architecture, Cardiff University. She has worked in practice as a consultant in Environmental Design and Architectural Science and is a member of the International Building Performance Simulation Association – IBPSA England. At the University, she leads the MSc Architectural Science Research (Research Methods) and coordinates the MSc Dissertations in the courses of Environmental Design of Buildings and Sustainable Mega Buildings. Her research focuses on the integration of building physics and machine learning into building design, collaboration in the AEC industry, design decision making and community-based design in developing countries. She has done extensive work in integrating building physics throughout the building design process in her teaching and research activities. This integration included not only looking at building performance simulation in conventional building design but also in examining how physics can be used in community design decision making.