Cultural Heritage and *Waste Heritage*: advanced techniques to preserve cultural heritage, exploring *just in time* the ruins produced by disasters and natural calamities

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Abstract

Cultural Heritage and *Waste Heritage* are the focus of different research activities, but they are linked by tragic happenings: disasters and natural calamities. A synthetic formulation defines that disasters occur when hazards meet vulnerability; surely this concept is strong when there is a human involvement but for us this parameter is measurable not only by the label *death toll*, but also by damages to the legacy of physical artifacts and intangible attributes of a group or a society: that is *Cultural Heritage*.

This paper introduces advanced techniques to preserve Cultural Heritage, exploring *just in time* ruins produced by disasters and natural calamities. The concept *just in time* is used to highlight the need to execute this activity during the first weeks/months after a negative event, to maximize the recovery phase before other alterations to the disaster site. Our research team is actually developing a small aerial drone to carry a payload devoted to explore L'Aquila city, which was strongly affected by the 2009 earthquake. This earthquake damaged about 10,000 buildings, leaving more than 65,000 people homeless.

In this paper we propose new methodologies to explore ruins using advanced technologies (e.g. Multi-Rotors aerial drones, High Definition infrared cameras, 360° one-click panoramic cameras/optics, etc.) and an integrated waste management approach to deal with the critical after earthquake phase (e.g. demolition, transport and temporary storage, recycling and final disposal).

Keywords: waste management, waste heritage, cultural heritage.

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1 Introduction

Italian law, according to the Council Directive 91/156/EEC, defines waste as *any substance or object (...) which the holder discards or intends or is required to discard* [1]. So emphasis is given to the holder's voluntary act of discarding his own property.

This definition is true in everyday life, but it is no longer applicable for disasters or natural calamities. In such circumstances there is no intentional act by citizens to *discard* their own belongings; a casual event forces them to move away from their estates. Rather, local governments consider ruins as waste, although in most cases the bonds between person and lost properties are evident.

When these events occur, the concepts of Cultural Heritage [2] and Waste Heritage melt into *Disaster Heritage*, where two aspects are predominant:

- populations binding with everything around them before catastrophes, linked to remembrance will;
- rubble removal in order to enable reconstruction and to allow the city tissue to start living again.

Historically in many catastrophic events the population showed the will to remember memories of their belongings; elimination of these memories produces new communities without any identity [3]. Nevertheless different government departments that are responsible for post-disaster phases management have systematically neglected any remembrance will.

Therefore reconstruction, to be effective, should not be focused only on building new homes but it must also consider the population's Cultural Heritage in which all citizens can continue to reflect themselves. Cultural Heritage is partly located in historically significant buildings, but mostly it lies in house rubble. House rubble should not be considered just waste, because it is charged with subjective importance that is called Heritage.

European and National waste policies are in general forced to reduce landfill disposal and therefore they push waste reuse, recycling or other recovery solutions. Furthermore, they have a tendency to adopt more restrictive measures for mining activities and therefore have increasing difficulty obtaining quarry materials for construction; reuse and recycling of demolition quarry could be a solution for all these problems.

Instead, after disasters or natural calamities, debris removal was addressed on the opposite side of national laws on waste disposal [4]; the need to speed up reconstruction justifies this behavior and at the same time shows two negative aspects:

- lack of procedure and, therefore, of established planning operations for catastrophic events;
- impossibility of recovering Cultural Heritage from each house debris and, in most cases, even not an effective secondary raw materials recovery from rubble to be reused during reconstruction.

Hence in this paper we propose a methodological approach, which is typical of remediation processes, in order to reconcile two disaster heritage predominant aspects and that can be adopted in any catastrophic event.

2 Methodological approach

The proposed methodological approach consists of four steps in temporal sequence and each one is preparatory to next: the first one is the preliminary investigations followed by the cognitive phase; the third one is the design step and, finally, there is the reuse/disposal phase.

2.1 Preliminary investigations

Preliminary investigations have the purpose of determining the logistic aspects in order to optimize the next steps.

Obviously in the early hours post-disaster all efforts must be focused on saving lives; but after this priority authorities have, necessarily, to proceed with the first phase so as to expedite reconstruction and to prevent damaged site alteration risks. So it is necessary explore *just in time* ruins produced by disasters and natural calamities in order to preserve Cultural Heritage. The concept *just in time* is used to highlight the need to execute this activity during the first weeks/months after the negative event (as soon as the disaster magnitude makes it feasible) in order to maximize the recovery phase before other alterations of the disaster site.

The first phase activities are:

- to acquire data by electro-optical devices and to estimate debris volumes;
- to define the road situation to access damaged sites and remove rubble;
- to identify areas for temporary storage and final disposal;
- to classify rubble commodity.

It is appropriate to emphasize that electro-optical devices surveys of houses are already useful to citizens in order form them to remember and ensure that their historical memories are not lost; in this way Cultural Heritage can be preserved.

2.2 Cognitive phase

The aim of the cognitive phase is to classify buildings to be demolished in terms of:

- materials (concrete, masonry, mixed),
- building technology,
- structural type,
- position (isolated, interior, extremity or corner building),
- type and static behavior of roof: heavy or not heavy pushing, light or not light pushing,
- structural details, particularly of masonry buildings: the presence of vaults, chains, curbs etc.

During this stage, tests will be run to characterize the chemical, physical and mechanical properties of materials and to assess their reuse or, alternatively, their disposal.

Finally, it will possible to create a materials archive in terms of resistance and photos to use the data for future statistical research dedicated to interpreting the causes and dynamics of collapses.

2.3 Design step

This step is the core of demolition aspects and it is needed to preserve the safety of the surrounding buildings, even designing temporary reinforcement works. Structural elements will be detected in detail to in order to determine which buildings should not be demolished and so they must be safely preserved in case of partial demolition.

Particular attention should be paid to the demolition of buildings containing hazardous substances, such as asbestos. As such, the health of citizens and of employers in demolition activities will be safe and the contamination of nearby buildings will be avoided and appropriate disposal must be found.

All processes and performances required for building demolitions will be evaluated and guidance provided in order to improve the cognitive phase, such as information for materials tests.

Moreover, where it is possible, a selective demolition will be carried out; this means proceeding in the opposite way to building operations. This activity will produce materials separation in homogeneous fractions in order to achieve a major reuse of materials percentage; eventually recovered materials can be sent to an enhancement appropriate treatment before reusing them.

Finally, while demolitions occur, owners or their representatives will be there to recover assets from the rubble, or any element that can preserve historical memory.

2.4 Reuse/disposal phase

The reuse/disposal phase will consist of treating operations, such as the selection, sorting and volume reduction of debris or materials not originated from selective demolition. This step will be held before disposal or recycling/recovery final operations in areas identified for temporary storage.

Technologies currently on the market could make use of at least three different product categories, starting from an undifferentiated rubble input: stones sorted by sieve sides, metallic materials and light fraction (most paper, wood and plastic). Selection plants are usually characterized by standard solutions for crushing, sieving, and iron removal stages; while the decision to select the light fraction depends on the recycling level that would be pursued [5].

Materials reusable in the post-catastrophe reconstruction phase are agglomerations for concrete and masonry, mostly found in historic buildings; however, they have to meet specific technical features imposed by law and, thus, they can be defined as secondary raw materials.

Something different has to be done for any steel element from demolition because its direct reuse is not permitted; however, all steel can be usefully recycled in the transformation steel process.

Finally, each demolished site, which may include one or more housing units, will be treated individually so that any personal effects, such as ornaments, photographs, paintings, books, etc, can be recovered. All recovered objects, also in previous phases, will be categorized according to source, and the details stored on an accessible website so as to make them available for possible recognition by owners.

3 Advanced technologies for ruins exploration

Aerial platforms and specific sensors are needed in order to achieve the phase objectives of the preliminary investigations and to have a quick overview of damaged sites.

This third dimension vision is capital to bringing support for decision making and to explore *just in time* ruins, avoiding losing time during the hectic period after disasters.

Today, how to place helicopters or airplanes above areas is well known, but the cost of using these machines is very high and, most of the time, they rely on physical persons to transmit images, when possible.

Currently a wide variety of aerospace platforms (satellites, aircraft, helicopters, unmanned aerial systems, etc.) are available to monitor environmental problems, but their real effectiveness is often limited due to platform capability and on-board sensors [6].

To perform an aerial monitoring of the sites damaged by disasters and natural calamities, usually, the required altitude is low due to moderate geographical extension of the interested area.

Figure 1 shows an example of the mission profile developed to examine the L'Aquila city area, which was damaged by a recent earthquake.

The first step is the matching of the critical areas defined by the earthquake epicenter and the critical areas defined by the status and typologies of buildings and structures (age, materials, etc.).

The second step in the mission profile will define a 3D flight path close to the target in order to acquire high-resolution data. It is important to highlight that the aeronautical platforms have to fly in a very critical environment (close to the ground and often in urban/sub-urban areas); moreover, in this scenario, the platforms ought to have high maneuverability (compliant with the "see & avoid" onboard system) and they should be able to perform low velocity (possibly hovering) to easily track the target.

Due to these constrains, UAV Multi-Rotors with an appropriate payload are the core of the system to match the requirements.

3.1 Multi-Rotor aerial drones

Multi-Rotors are an emerging rotorcraft typology for Unmanned Aerial Vehicle (UAV or UAS).

The vehicle consists of four, six, eight, etc. rotors in total, which usually have two pairs of counter-rotating, fixed-pitch blades located at the same distance from the aircraft mass center.

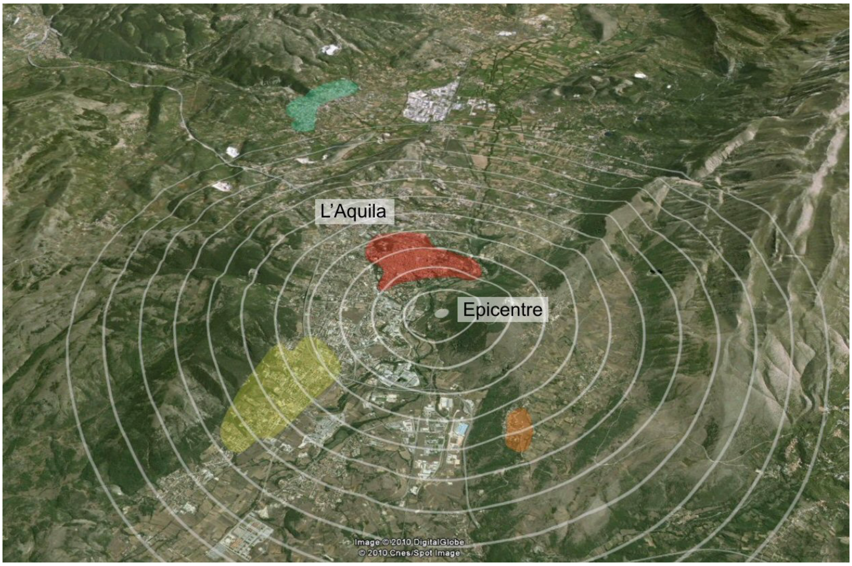

Figure 1: L'Aquila earthquake epicenter and the overlap of other crucial data (critical areas, DEM information, etc.).

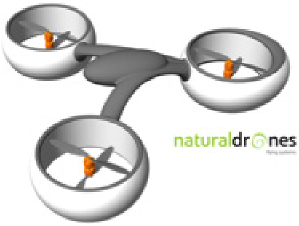

Figure 2: The Multi-Rotors aerial drone proposed.

Due to its specific capabilities, the use of autonomous Multi-Rotor vehicles has been investigated for a variety of applications, both as individual vehicles and in multiple vehicle teams, applied to surveillance, search and rescue and mobile sensor network domains.

We cooperated with CIRA - Italian Aerospace Research Center in the definition of the requirements of a new Multi-Rotors platform developed by the NaturalDrones Company.

The platform proposed is shown in fig. 2; its total weight is in the range of 1500 to 2500 g and maximum endurance is 15 minutes with a payload of 600 g or 25 minutes in the case of a 300 g payload. This aerial system has GPS way-points navigation and a parachute as a fly termination system; furthermore, it is able to perform vertical take-off and landing (VTOL) in order to be operated directly from mobile ground control stations in unprepared terrains with vehicles similar to those used by rescue and intervention teams.

The Multi-Rotors aerial drones are intrinsically safe, with low kinetic energy due to low velocity and low weight and, for these reasons, they are suitable for monitoring sites damaged by disasters and natural calamities.

Moreover, the system developed to perform our missions is a six rotors with a special frame/shell that protects the propellers from breaking during collisions and permits flights in obstacle-dense environments with a low risk of damaging aircraft and people being "touched".

The proposed aerial platforms, flying between buildings in urban areas, will be able to explore *just in time the* ruins and, with tanks specialized to the payload, they will acquire important data in real time (e.g. debris volumes, road situation to access damaged sites and remove rubble, etc.).

All data collected during the mission will permit one to build an important database that will be crucial to preserving Cultural Heritage in a post-event phase.

Today the Italian Aerospace Research Center is developing a system, called "Aerospace Interoperability Framework", that provides a complete framework composed of flight and ground segments, communication links, acquisition sensors, mission paradigm logic and scheduling, data acquisition paradigm, logic and data processing; this integrated system is the technological solution that matches our mission profile.

Figure 3: First prototype of the frame/shell.

Figure 4: First flying prototype (without frame/shell).

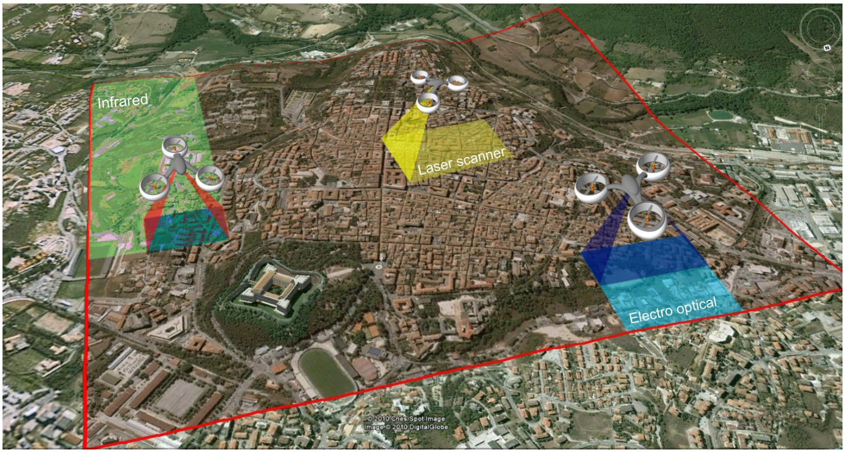

Figure 5: Example of aerospace interoperability framework applied to the L'Aquila area exploration/monitoring.

3.2 Payload

The aerial platforms and related systems to control and manage them are only a part of a complex system where the payload is the conceptual link between the target and mission objectives.

In our system the payload includes an array of sensors finalized to environmental measurement and it was customized to be hosted on board the proposed UAV.

The systems carried onboard the Multi-Rotors include: electro-optical devices, electro-chemical/biochemical devices, GPS, Data Logger, wireless data link and a complete micro-PC to collect, analyze, manage and store data on board.

Even if all components of the payload are fundamental to obtaining a synergy effect to reach the result, two components of the proposed system are essential in the discovery phase during the flight over the ruins: HD IR digital camera and 360° one-click panoramic camera.

3.2.1 High definition infrared digital camera

Thermal imaging displays the amount of infrared energy emitted, transmitted, and reflected by an object: Incident Energy = Emitted Energy + Transmitted Energy + Reflected Energy.

Incident Energy is the energy profile when viewed through a thermal imaging device, Emitted Energy is generally what is intended to be measured, Transmitted Energy is the energy that passes through a subject from a remote thermal source, and Reflected Energy is the amount of energy that reflects off an object's surface from a remote thermal source [7].

The effectiveness of infrared thermography could also be augmented using aerial platform; in fact, if we change the altitude of thermal-sensor (IR-camera), it increases the FOV (field of view) in an acquired scene and we obtain a direct thermal comparison of targets with other objects in the scenario [8]. For these reasons, aerial infrared (IR) thermography exceeds the current limits of traditional methods of detection [9].

This means that each object has its thermal infrared signatures; so, based on the thermal infrared spectrum due to differences in the temperature of elements, first of all it is possible to save lives in the early hours post-disaster. Later, it will be used for pre-classification of buildings, based on rubble commodity, during preliminary investigations.

The HD IR digital camera used in our activities is the model SC660 manufactured by FLIR Systems. Each radiometric image has a resolution of 640x480 pixels; each pixel also corresponds to a value of temperature or emissivity, which is stored in a matrix of data (quantitative). The matrix is easily re-usable for further processing with software tools such as MATLAB and Excel, as well as infrared thermography software (ThermaCAM Researcher, ThermaCAM Reporter professional, Quick plot etc.).

Other main technical specifications of this IR camera are:

- Thermal Sensitivity: <45 mK;
- High accuracy +/- 1%;
- Dynamic Details Enhancement (DDE);
- Built-in GPS;
- WLAN remote control and display;
- 3.2 megapixel visible light camera (this feature permits a data-fusion between IR and Visible).

3.2.2 360° one-click panoramic digital cameras

Until today, taking a 360° panorama with a standard camera has required taking multiple shots while rotating the camera slowly and then combining (stitching) those shots together to form the panorama.

In contrast, the 360° full-circle lens allows the full 360° surroundings of the camera to be imaged at the same time with a single lens.

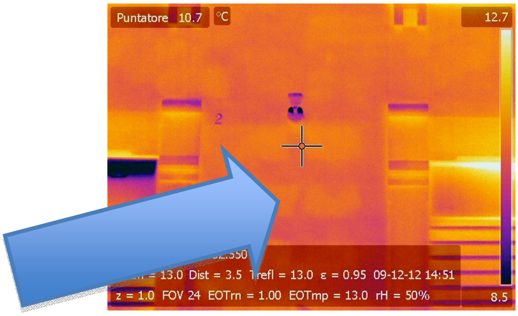

Figure 6: Example of structural damage discovered by a radiometric image that is invisible with a standard camera shot.

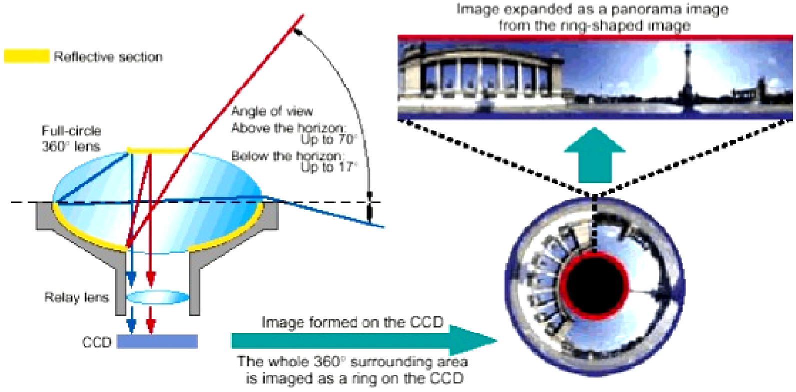

Figure 7: Sony full-circle 360° lens mechanism.

Figure 8: Sony MHS-PM5D 360° full-circle lens.

The digital camera selected by us is the MHS-PM5D HD model manufactured by SONY; with a special lens cap this camera is able to save a detailed panorama (photo/video) of damaged sites in one click.

The main technical specifications of this model are:

- Photo resolution: 5 Mp
- Video resolution: 1920x1080 pixels
- Digital Zoom: 4x;
- Focal Distance: 7.0mm;
- Focus: Fixed Focus ;
- Shutter Speed: 1/15 - 1/4000

The weight of approximately 110g - 130g and the size of 19x108x54 mm make this camera suitable for being used as the payload of the Multi-Rotors aerial drone proposed.

The joint use of these devices and UAV Multi-Rotors generates an advanced technology for ruins exploration that will be useful for preliminary investigations and the cognitive phase and fundamental to create a 360° video/photo archive.

Figure 9: Example of a simulated mission performed by UAV Multi-Rotors to preserve the cultural heritage exploring *ruins just in time*.

4 Conclusions

Many scientists are surveying the damage in a post-event with high-tech sensors, sometimes integrated into aircrafts or rotorcraft, but often these new technologies are used only to support search and rescue activities.

This paper introduces advanced techniques to preserve Cultural Heritage exploring *just in time* ruins produced by disasters and natural calamities. The concept *just in time* is used to highlight the need to execute this activity during the first weeks/months after a negative event, in order to maximize the recovery phase before other alterations to the disaster site.

Our research team is actually developing a small aerial drone to carry a payload devoted to exploring areas affected by disasters and natural calamities.

The *test bed* of our simulation and research activities is L'Aquila city, which was strongly affected by the 2009 earthquake.

The proposed system using the data collected will permit one to produce information maps for relief and recovery agencies and, above all, help the citizens to remember memories of their belongings and, finally, to ensure that their historical memories are not lost; in this way Cultural Heritage can be preserved.

Finally, it is important to highlight that the procedures and technologies developed in our research activities are essential to support an integrated waste management approach to deal with the critical after earthquake phase (e.g. demolition, transport and temporary storage, recycling and final disposal).

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