

# 3D imaging to improve damage restorations: the case of the Papal Basilica and Sacred Convent of Saint Francis in Assisi, Italy

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**ABSTRACT:** One of the main problems of emergency management in case of damage reported by historic buildings after an earthquake is represented by immediate damage assessment. In fact, nowadays it is not possible to use techniques other than the personal evaluation carried out by first responders.

The purpose of this paper is to illustrate a proper 3D imaging technique to improve damage restorations, showing, as a case study, what has been done and what is going on in the Papal Basilica and the Sacred Convent of Saint Francis in Assisi, Italy.

## 1 INTRODUCTION

### *1.1 Definition of the context*

One of the main problems of emergency management in case of damage reported by historic buildings after an earthquake is represented by immediate damage assessment. Nowadays, it is not in fact possible to use techniques other than the personal evaluation carried out by rescuers. However, since in many cases it is necessary to estimate the deformations and displacements of structures based on objective values within a brief time, the Department of Fire Corps of the Italian Ministry of the Interior and the research sector have started to study alternative solutions, using innovation technologies.

One of the methods under study is represented by the use of 3D images of the buildings acquired before the events and their comparison with similar images acquired after the events.

### *1.2 Emergency managements needs*

The management of the emergency in the calamities that concern the cultural heritage constitutes a discipline not sufficiently studied at international level. In fact, there are not many countries where a relief agency is frequently interested in securing cultural or historical heritage damaged by natural or anthropogenic events.

In Italy, the wide availability of the historical artistic testimonies spread throughout the national territory and the presence of hydrogeological and seismic risk factors on almost the entire territory have led the National Fire Corps (Italian acronym: CNVVF) to define over the years more specific skills concerning the securing of damaged cultural heritage (D'Ambrogio et al., 2016; Marsella & Marzoli, 2016; Marsella & Marzoli, 2017; Marsella et al., 2017).

In particular, the seismic events that hit central Italy in 2009 and in 2016 highlighted the need to have personnel able to operate in emergency conditions with specific operating procedures to shore up, as soon as possible, the most part of buildings to allow the following repair and restoration activities.

Among the techniques of securing, the most used is certainly represented by the construction of shoring and roofing, to prevent the seismic shocks after the first one, since meteorological events can accelerate the destructive work in the event of an earthquake.

To carry out these activities, however, the prerequisite is that the level of damage suffered by

the structures, usually in masonry, has been assessed as exactly as possible. This assessment, in fact, is necessary both for the safety of the operators and for the definition of the type of propping structure to be installed.

Until now, the assessment could only be based on the visual estimate of the damage suffered by the structures by the rescue personnel. This method, due to the personnel operating in safety conditions, led to overestimating the extent of the damage. On the other hand, having precise assessments on the deformation displacements suffered by the damaged walls would lead to identify the most suitable measures to operate and define more efficiently the material necessary to implement the shoring.

It is important to note that the National Firefighters Corps, according to the type of damage suffered by a building, has already made available to the first responders some manuals for the construction of the shoring works in emergency. These manuals (called STOP cards) integrate the standard operating procedures and constitute the most effective tool in the management of the emergency, together with the logistics chain that makes it possible to bring the material where and when it is needed, optimizing the distribution when these kinds of catastrophic events affect a wide area.

### *1.3 Use of 3D images in emergency*

What can be a use of innovative technologies to improve relief in case of earthquakes or other events that damage historic buildings or cultural interests? One possible answer is to allow first responders to acquire 3D images of adequate accuracy to compare with images of the same damaged building parts acquired before the calamitous events. In fact, the tools currently available are such as to allow, even under the point of view of economic sustainability, the use of equipment able to acquire images that provide the 3D of the buildings by rescue teams. Similarly, systems have been available for years to reach data bases held in remote locations (cloud services). The hypothesis on which the CNVVF is working is represented, within the STORM project, by the realization of an infrastructure that allows to acquire at any time the 3D image of the part of the building affected by the event to compare it with an image detected during the phases of emergency. This hypothesis presupposes that (a) a homogeneous format of the 3D images is available, (b) that these 3D images are accessible on a computer infrastructure available at any time, (c) that first responders can acquire and process 3D images on the scenario of emergency and (d) that they are able to practice the comparison between the images to appreciate the deformations suffered by the building.

The experimentation carried out within the H2020 European Union research project STORM (Safeguarding Cultural Heritage through Technical and Organisational Resources Management) has shown that actually there are no technological obstacles to the development of such operating procedure. A possible application case is represented by the Papal Basilica and Sacred Convent of Assisi in Italy which has been severely damaged by the 1997 earthquake, due the high seismic risk of the area.

In the considered site a plenty of activities have already started and are still going on, such as laser scanning, to set up a proper Integrated Multidisciplinary Model for Safety and Security Management (IMMSSM) and Integrated Technological System Framework based on Internet of Everything (IoE-ITSF) to support it (Gambetti et al., 2017a).

The IoE-ITSF can also support the realization of a proper integrated 3D image-based tool to let the CNVVF understand faster and more accurately the degree of safety of the structures in case of emergency.

## **2 THE PROJECT FOR THE PAPAL BASILICA AND SACRED CONVENT OF SAINT FRANCIS IN ASSISI IN ITALY**

### *2.1 The Papal Basilica and Sacred Convent of Saint Francis in Assisi*

The Papal Basilica and the Sacred Convent of Saint Francis in Assisi in Italy is visited, each year, by millions of pilgrims and visitors coming from all over the world.

It embodies a unique cultural heritage site where the mortal remains of Saint Francis are housed since 1230 A.D. and it has been appointed as World Heritage by UNESCO from 2000 A.D., together with other Franciscan sites in the surrounding and the entire Assisi town.

The Papal Basilica, is composed by three superimposed layers, represented by:

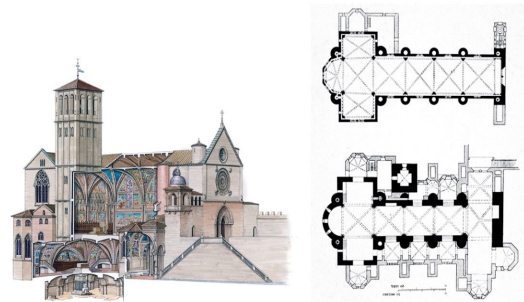
- 1) the tomb or crypt of Saint Francis, located at the lower level,
- 2) the lower Basilica, whose altar is just above the tomb of Saint Francis,
- 3) the upper Basilica, located above the lower Basilica.

Inside the upper and lower Basilica unique frescoes by Giotto and other famous painters are present.

Into the Sacred Convent there is a museum, a library and a plenty of other spaces to hold spiritual and cultural activities. Inimitable and composite cultural heritage sites, as the considered one, require a remarkable effort to guarantee security and safety of visitors, considering also natural catastrophic events such as earthquakes, since that zone is characterized by a quite elevated level of risk from this point of view. Along with such needs are cultural heritage preservation and protection as well as accessibility for visitors, with reference to visitors with disabilities, and for personnel normally present for site management, including the Friar's community. From this point of view, it is necessary to consider other important aspects such as energy management, maintenance management and a plenty of other aspects that must be managed in a well-ordered way, by means of a suitable Technological System Framework based on Internet of Everything (IoE-ITSF) that is able to support a proper Integrated Multidisciplinary Model for Safety and Security Management (IMMSSM) (Gambetti et al., 2017a).



(a)



(b)



(c)



(d)

Figures 1. (a) Panoramic view of the Papal Basilica and the Sacred Convent of Saint Francis in Assisi. (b) Schematic section view of the Basilica. (c) View of the interior of the upper Basilica where the Giotto's frescoes are visible. (d) View of the interior of the lower Basilica.

## 2.2 Description of the project

The IoE-ITSF system must be able to implement and support an integrated multidisciplinary model for security and safety management (IMMSSM) (Garzia, 2016; Garzia & Lombardi, 2017), for the considered site, by means of a multidisciplinary approach schematized in Fig.2. It must also be able to provide all the present and future IoE services planned, which of connecting people, things (mobile terminals, smart sensors, devices, actuators; wearable devices; etc.), data / information / knowledge and specific processes (Garzia et al., 2011; Contardi et al., 2011; Garzia & Cusani 2012a; Garzia & Cusani 2012b; Garzia et al., 2012; Garzia & Papi, 2016; Garzia & Sant'Andrea, 2016; Di Martino et al., 2017; Garzia, 2017), such as the emergency management service that represents the goal of this paper.

The IMMSSM is developed according to the following items: risks analysis, impact analysis, risks mitigation and residual risks management (Guarascio et al., 2007; Norman, 2010).

Risks mitigation can be achieved by means of essential operative factors or tools (OTs) that are represented by: countermeasures (physical/logical technology, and physical/logical barriers) and Security/Safety policies and procedures, considering also human factor and psychological aspects (Borghini et al., 2016; Garzia, 2013).

Residual risk management can be achieved by means of essential tools, aided by OTs, that are represented by: emergency management, service and business continuity, disaster recovery.

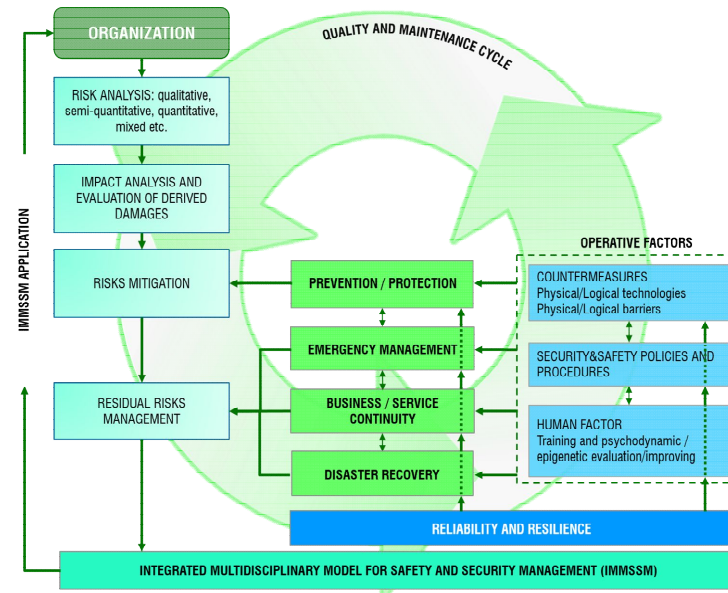


Figure 2. Scheme of the Integrated Multidisciplinary Model for Safety and Security Management (IMMSSM).

The IMMSSM can be implemented and supported using the above mentioned Integrated Technological System Framework based on IoE (IoE-ITSF) which allows the complete operativity of the IMMSSM with high modularity and flexibility. In this way, it is possible to translate any eventual adjustment of the IMMSSM into a fast and low-cost adjustment of the IoE-ITSF at any time, guaranteeing always the best actions of IMMSSM and the opportunity of providing the strategic IoE services. The aim of the IoE-ITSF is to ensure: the maximum level of security and safety of people and of tangible and intangible assets, the maximum integration of all the 'IoE objects' to generate high intrinsic-value solutions characterized by an optimal cost/benefit ratio, the maximum ease of operation, using local and remote automation systems, the maximum level of reliability, resilience and flexibility, the maximum level of modularity and expandability, including IoE services. The proposed IoE-ITSF is schematized in Fig.3.

The system is characterized by a high modularity which allows for the adding of any device, element, system etc. that needs to be integrated in the IoE system at any time. The IoE-ITSF is planned to be a general system useful for most of organizations and, for this reason, it can also plan for the presence of external visitor's presence. For security reasons, the networks used to perform supervision, control and security/safety services, internal personnel services and visitor's services are properly separated by physical and logical points of view. The different wired networks serve the different access points that ensure Wi-Fi services to security/safety and control personnel, internal personnel, including the Community of Friars, and visitors, increasing the security level of the communication and the protection of the system against cyber-attacks (Garzia, 2013).

The system can communicate with all the 'IoE objects', signalling any dangerous or critical situation to the operators (security / safety personnel, maintenance personnel, Fire Brigades, Police, Civil Protection, Medical etc.), in real time, using any resource of communication available.

A suitable privacy-compliant app, designed for the site, can be installed directly by security / safety personnel, internal personnel, including the Community of Friars, and visitors on their

mobile terminals directly when they arrive in the site or in advance. This app allows access to all services planned for the user profile (general and augmented reality information, security & safety information, positioning services useful for emergency management, VoIP services for ordinary, security & safety and emergency communications with the related personnel, etc.) and permits the system to consider the mobile terminals as 'IoE objects' to achieve the precise desired purposes of the considered organization. The app allows to position people using both GPS system of mobile terminals and the Wi-Fi positioning capability of the system, which can operate correctly even in underground environments where the GPS signal is shielded or weak. In this way, it is possible to manage any kind of emergency, communicating directly with people, if necessary, using the text and VoIP functionalities of the app. The IoE-ITSF is equipped with all the countermeasures necessary to prevent cyber-attacks, by means of suitable-installed firewall / intrusion detection system / anti-virus devices and other prevention/protections countermeasures (Garzia, 2013).

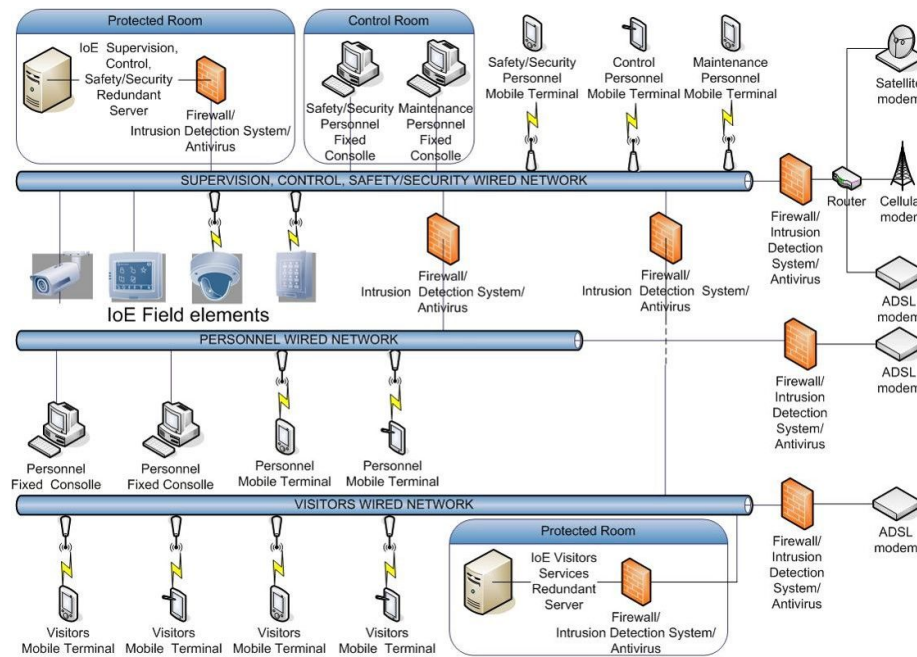


Figure 3. Scheme of the Integrated Technological System Framework based on Internet of Everything (IoE-ITSF) to support the IMMSSM.

### 2.3 Activities for the development of the model and the design of the Integrated Technological System Framework based on Internet of Everything (IoE-ITSF)

A plenty of various actions have been carried out and are still going on both in parallel and sequentially as a function of the existing resources, focusing always towards the final aim. For this reason, a certain number of preliminary and indispensable multi-disciplinary activities formulated as set up of the IMMSSM and subsystems of the IoE-ITSF are considered (Gambetti et al., 2017a). Because of the multi-disciplinary work that have been done and that is going on, an international group has worked and is still working, both locally and remotely.

First of all, the initial activities essential to set up the IMMSSM have started, included the other activities necessary to study, design and realize the IoE-ITSF for the considered site.

In particular, since it was required to obtain all the necessary information to be shared, both locally and remotely, by the international working group, an appropriate laser scanning activity of the Papal Basilica and of the Tomb (Figures 4, 5, 6) has been done (Garzia et al., 2018). It is aimed at obtaining a 3D model of it that is going be rendered into a Building Information Modelling (BIM) and to utilize a flexible tool for all the needed activities, including safety and security management (Garzia & Lombardi, 2018). This action is essential due to the presence of strong architectural restrictions, which involves also taking care in the installation of wires and devices (Garzia & Cusani, 2013).





Figure 4. Tomb point cloud represented in Revit Environment.

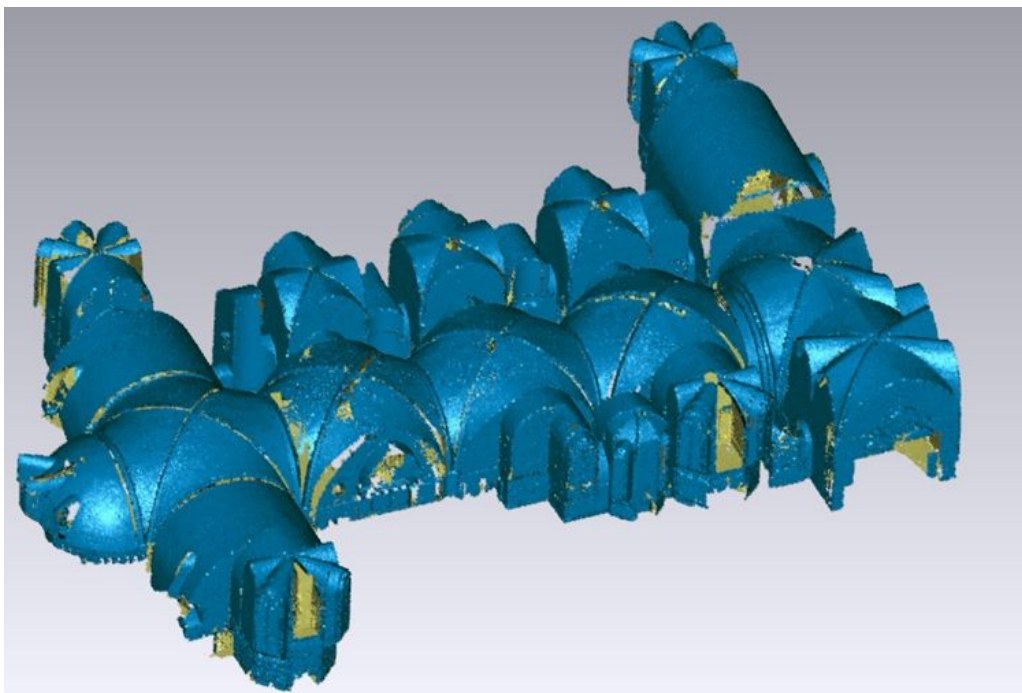


Figure 5. Meshing of lower Basilica.

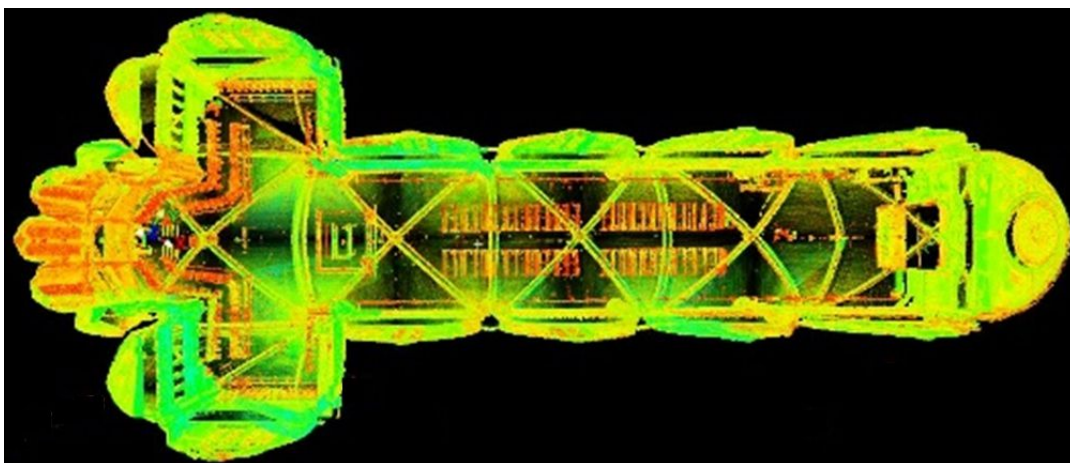


Figure 6. Point cloud of upper Basilica.

Further, it has started the study, the design and the realization of the new communication network which is essential to guarantee that all the information needed for the strategic IoE services could be supported with the required level of security, safety, reliability and resilience, granting the required confidentiality, availability and integrity (Gambetti et al., 2017b).

As shown in fig. 7, the network is based on apt communication smart nodes (SNs) densely linked via optical fibres so that, in case of a malfunction of one SN, only the functionality of IoE elements linked to the considered node are lost, while any communication route is rapidly recovered via the other nodes. Each SN is composed of separated devices for safety/security services, personnel services and visitors' services to guarantee physical and logical separation between the different classes of services. The different wired networks serve the different Access Points that ensure Wi-Fi/IoE services to security/safety/control personnel, internal personnel and visitors, increasing the security level of the communication and the protection of the system against cyber-attacks (Garzia, 2013).

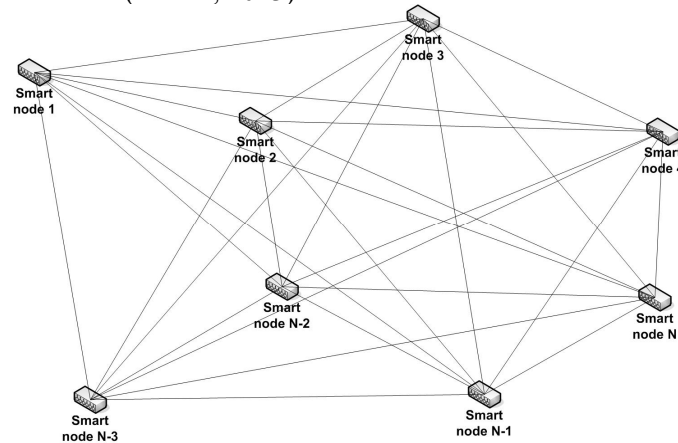


Figure 7. Architecture of the IoE system backbone network.

Each SN is supported by a proper electrical back up system (UPS) which allows it to work properly even in the absence of the main electrical power. Further, each SN has a reliable and resilient communication system capable of using cellular connections which allows it to operate also in case of catastrophic events such as earthquake, fires, etc. Some of the SNs use a proper communication device that allows it to utilize satellite connection, even if with reduced band width. Different kind of SNs are planned, as a function of the IoE services they must provide, mixing together the following devices/functionalities: switching, computation (node server), cellular communication, satellite communication, etc. Thanks to this flexibility, the SNs can work and communicate using also the external wireless connections, in case of a malfunction of the wired network, using a distribute intelligence scheme.

A suitable Genetic Algorithm (GA) based technique has been studied and tested to design the connections between the different IoE Field Elements and the different smart nodes that constitute the network to ensure a decrease of final costs and an elevated level of reliability and resilience of the system itself, considering the typical artefacts and restrictions of an incomparable cultural heritage site such as the considered one. The new network is also essential for emergency management, that is the scope of the paper by means of a suitable 3D imaging technique.

Other activities are dedicated to new and suitable IoT/IoE services for the considered site such as: microclimate monitoring (Garzia & Culla, 2017); human factor and psychological aspects; people counting subsystem which represents a fundamental tools for emergency management; Augmented Reality (AR) and Virtual Reality (VR) intended at improving the visiting experience of the visitors; biometric solutions for the considered site, with particular care to the privacy aspects; fluid dynamic analysis of the interior of the site to improve the quality of air with regards to people wellness and pictures preservation plus further activities related to the energy management/optimization/preservation and renewable energy; cybersecurity aspects of the IoE system; Big Data (Kleppmann, 2017), security analytics for Big Data infrastructure, machine learning techniques for the site etc., with the purposes of attainment, step by step, the desired goals.

### 3 THE PROPOSED 3D IMAGING SYSTEM TO IMPROVE DAMAGE RESTORATIONS

#### 3.1 Introduction and purpose

The purpose of the proposed system is to allow the Italian National Fire Corps (CNVVF) personnel to use 3D images to improve one of the most critical aspects of rescue interventions involving any kind of buildings. In fact, when first responders are called in case of earthquake or risk of collapse of a building, they must rapidly assess the stability of the structure. In such case, ordinary tools are not useful, and it is necessary to find more suitable tools. Nonetheless, an evaluation must be done, due to the risk for people or cultural heritage. From this point of view, the STORM project research is testing the viability of using the already existing laser scanning data of the considered site and repeat again such activities to compare the results with already existing results. Any variation derived rapidly on the site from the comparison could immediately provide useful and first level information regarding possible damages. Further, since the IoE-ITSF of the considered site is designed to be reliable and resilient, it could support CNVVF providing not only in real time all the data necessary for laser scanning data comparison but also powerful tools for emergency management, as illustrated above.

#### 3.2 The integrated system for 3D imaging technique to improve damage restorations

The purpose of the proposed integrated system is represented by the possibility of comparing 3D images collected via laser scanning before the possible damage with the images that the first responders (in this case, CNVVF) acquire on the rescue scenario using their own instruments. The integrated system has been designed to be applicable even in other contexts, to represent a new and general framework for this kind of applications since it can operate with the support of local and/or remote subsystems but even in a stand-alone modality, ensuring an elevated level of reliability and resilience. The general scheme of the integrated system is shown in fig. 8.

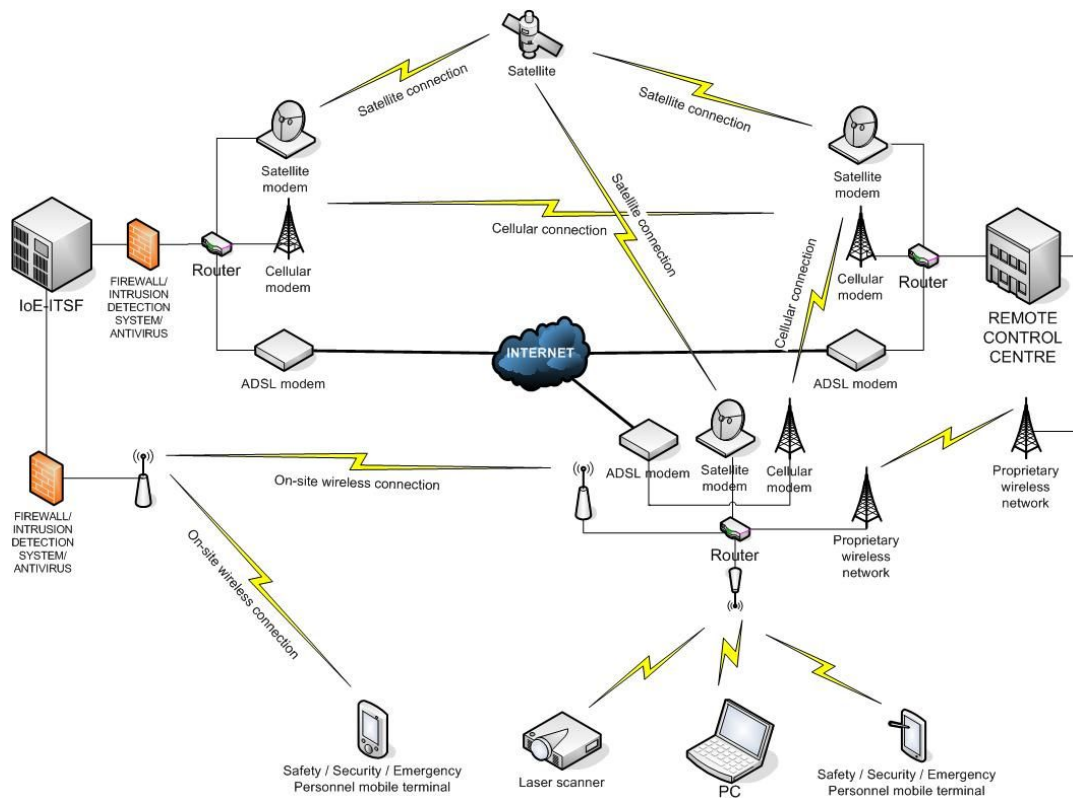


Figure 8. Architecture of the 3D imaging system to improve damage restorations.

As it is possible to see from fig.8, the IoE-ITSF and the Remote Control Centre for Emergency Management (RCC) are connected both in ordinary and emergency conditions, using the multiple, reliable and resilient communication channels (ground ADSL, cellular and satellite connections) already available in the IoE-ITSF itself.

3D laser scanning images (3DLSIs) are available both locally, properly stored by the IoE-ITSF,



and remotely, since there can be a back-up in the RCCEM.

In case of emergency, all the pre-event 3DLSIs are properly transferred into the mobile units of emergency personnel that must give first responds on the field, to be sure that, when they reach the site, all the necessary data for comparison are available. Anyway, they can always exchange data and information using the remote communication channels of the RCCEM (ground ADSL, cellular, satellite connections or proprietary wireless network) or the suitable on-site wireless connection of the IoE-ITSF.

In this way, a part the fundamental use of local wireless network of IoE-ITSF, and all the related advanced IoE services illustrated before (to actuate all the necessary emergency operations), once the CNVVF personnel have done all the necessary post-event 3DLSIs, they can start immediately the comparison using the local computation resources of the IoE-ITSF. If the IoE-ITSF wireless connections is not available, due to strong possible damages of the catastrophic event, they can try to use the other communication channels with the RCCEM to send data to be compared. If these last channels are not available, they can always use their mobile terminals or computation resources carried on the site to do all the necessary comparison operations.

Thanks to the proposed integrated architecture that uses IoE-ITSF, RCCEM remote resources and local/mobile resources, working according to the procedures illustrated above, it is always possible to execute the necessary comparison between the 3D laser scanning images before the event and after the event, so that it is possible to evaluate for the first responders any risk from the structural point of view in a fast and reliable way.

In this way, the rescue operation procedures carried out by the CNVVF will have the possibility to benefit of the integrated system. In fact, it will be able to provide in real time, during emergency operations, among the other data processed, 3D images acquired before the damages. In particular, the specific scenario currently being developed in the H2020 EU project STORM (<https://www.storm-project.eu>), is based on the capacity of: (a) acquiring images of the damaged parts of an historic building by the first responders through laser scanner equipment of the CNVVF; (b) ensuring the CNVVF to access, during the emergency, a proper cloud database that can provide the 3D data of the Papal Basilica and Sacred Convent of Assisi acquired; (c) comparing the images taken before and after the damages occurred, in order to improve the assessment of the structural safety condition of the damaged parts and decide the further activities to be carried out thanks to a deeper knowledge of the situation provided by the system.

#### 4 CONCLUSIONS

A 3D imaging system to improve damage restorations has been presented, together with the case study of Papal Basilica and Sacred Convent of Assisi in Italy.

The system has been designed to be applicable even in other contexts, to represent a new and general framework for this kind of applications since it can operate with the support of local and/or remote subsystems but even in a stand-alone modality, ensuring an elevated level of reliability and resilience in any situation. The studied system can be integrated into the system currently being developed in the H2020 EU project STORM aimed at improving the assessment capacity of the CNVVF in case of structural damages of cultural heritage buildings.

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