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## Integrated survey for the reconstruction of the Papal Basilica and the Sacred Convent of St. Francis in Assisi, Italy

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**Abstract.** The Papal Basilica and the Sacred Convent of Saint Francis in Assisi in Italy are characterized by unique and composite particularities that need an exhaustive knowledge of the sites themselves to guarantee visitor's security and safety, considering all the people and personnel normally present in the site, visitors with disabilities and finally the needs for cultural heritage preservation and protection. This aim can be reached using integrated systems and innovative technologies, such as Internet of Everything (IoE), which can connect people, things (smart sensors, devices and actuators; mobile terminals; wearable devices; etc.), data/information/knowledge and processes to reach the wanted objectives. The IoE system must implement and support an Integrated Multidisciplinary Model for Security and Safety Management (IMMSSM) for the specific context, using a multidisciplinary approach. The purpose of the paper is to illustrate the integrated survey for the reconstruction of the considered site that was necessary to obtain all the necessary information to start to set up the considered IMMSSM and the related IoE based technological system.

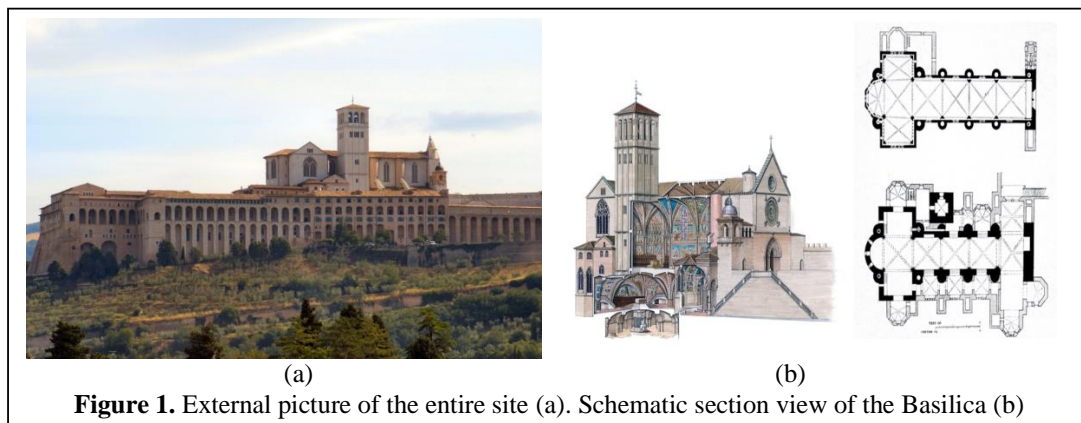
### 1. Introduction

The Papal Basilica and the Sacred Convent of St. Francis in Assisi, Italy, together represent a unique and specific cultural heritage site where the mortal remains of St. Francis have been housed since 1230 AD (Fig. 1). Millions of pilgrims and visitors from all over the world visit this site each year. In 2000 AD, together with other Franciscan sites in the surrounding area, it achieved UNESCO World Heritage status. Important international events, such as those related to world peace and dialogue between religions, are organized in this site and they are generally attended by thousands of people. The Papal Basilica, where unique frescos by Giotto and other famous painters are displayed, comprises three stratified structures represented by: the tomb of St. Francis, located at the lower level;



the lower Church, whose altar is just above the tomb of St. Francis; and the upper Church, located above the lower Church.

Inside the Sacred Convent there is a museum, a library and other spaces for hosting spiritual and cultural activities. Unique and composite cultural heritage sites, such as this, require a significant effort to ensure visitor security and safety. 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 an efficient way, using possibly a proper integrated technological system.



These aims can be achieved using integrated systems [1 - 5] and innovative technologies, such as Internet of Everything (IoE), which can connect people, things (mobile terminals, smart sensors, devices, actuators; wearable devices; etc.), data information / knowledge and processes [6 - 10]. The IoE system must also provide all the actual and future IoE services planned and implement and support an integrated multidisciplinary model for security and safety management (IMMSSM) [11, 12] for this specific site.

The purpose of the paper is to illustrate the integrated survey for reconstruct the considered site which was necessary to obtain all the necessary information to start the setting up the considered IMMSSM and the related IoE based system.

## 2. Integrated Technological Framework for IoE Services and IMMSSM

The proposed IoE system is designed to support an integrated multidisciplinary model for security and safety management (IMMSSM) [11, 12] for the considered context as shown in Fig.2a. In addition, it needs to be flexible to incorporate advanced IoE services and make provisions for the inclusion of future IoE services.

The IMMSSM is based on the following points: risk analysis, impact analysis, risks mitigation and residual risks management [13, 16]. Risks mitigation can be performed using fundamental operative factors or tools (OTs) which are represented by: countermeasures (physical/logical technology, and physical/logical barriers) and Security/Safety policies and procedures, considering also human factor and psychological aspects [17, 18]. Residual risk management can be done using fundamental tools, aided by OTs, which are represented by: emergency management, service and business continuity, disaster recovery.

The IMMSSM can be implemented and supported using a proper Integrated Technological System Framework based on IoE (IoE-ITSF) which allows the full functionalities of the IMMSSM with high elasticity. In this way, it is possible to translate any eventual modification of the IMMSSM into a rapid and cheap modification of the ITSF at any time, guaranteeing always the best performances of IMMSSM and the capability of providing the planned IoE services. The purpose of the ITSF is to

**(a) IMSSM Application**

The diagram illustrates the IMSSM application process, which is part of a **QUALITY AND MAINTENANCE CYCLE**. The process flow is as follows:

- ORGANIZATION** leads to **RISK ANALYSIS: qualitative, semi-quantitative, quantitative, mixed etc.**
- RISK ANALYSIS** leads to **IMPACT ANALYSIS AND EVALUATION OF DERIVED DAMAGES**
- IMPACT ANALYSIS** leads to **RISKS MITIGATION**
- RISKS MITIGATION** leads to **RESIDUAL RISKS MANAGEMENT**
- RESIDUAL RISKS MANAGEMENT** leads to the **INTEGRATED MULTIDISCIPLINARY MODEL FOR SAFETY AND SECURITY MANAGEMENT (IMSSM)**

The **INTEGRATED MULTIDISCIPLINARY MODEL FOR SAFETY AND SECURITY MANAGEMENT (IMSSM)** is supported by several **OPERATIVE FACTORS**:

- PREVENTION / PROTECTION** (linked to **COUNTERMEASURES: Physical/Logical technologies, Physical/Logical barriers**)
- EMERGENCY MANAGEMENT** (linked to **SECURITY/SAFETY POLICIES AND PROCEDURES**)
- BUSINESS / SERVICE CONTINUITY** (linked to **HUMAN FACTOR: Training and psychodynamic / epigenetic evaluation/improving**)
- DISASTER RECOVERY** (linked to **HUMAN FACTOR: Training and psychodynamic / epigenetic evaluation/improving**)
- RELIABILITY AND RESILIENCE** (linked to **HUMAN FACTOR: Training and psychodynamic / epigenetic evaluation/improving**)

**(b) IMSSM Architecture**

The architecture is divided into three main network layers:

- SUPERVISION, CONTROL AND SECURITY WIRED NETWORK**: This layer includes components like **IoE Supervision, Control, Security Redundant Server**, **Firewall/Intrusion Detection System/ Antivirus**, **Security Personnel Mobile Terminal**, **Control Personnel Mobile Terminal**, and **Maintenance Personnel Mobile Terminal**.
- IoE Field elements**: This layer includes **Firewall/Intrusion Detection System/ Antivirus** and **Intrusion Detection System/ Antivirus**.
- PERSONNEL WIRED NETWORK**: This layer includes **Personnel Fixed Console** and **Personnel Mobile Terminal**.
- VISITORS WIRED NETWORK**: This layer includes **Visitors Mobile Terminal** and **Visitors Mobile Terminal**.

The architecture also includes a **Protected Room** and a **Visitors Room**, both with their own internal networks and security measures. The entire system is supported by a **Reliability and Resilience** layer.

**Figure 2.** Scheme for IMMSSM (a). IoE based Integrated Technological System Framework (IoE-ITSF) enabling current and future technologies (b).

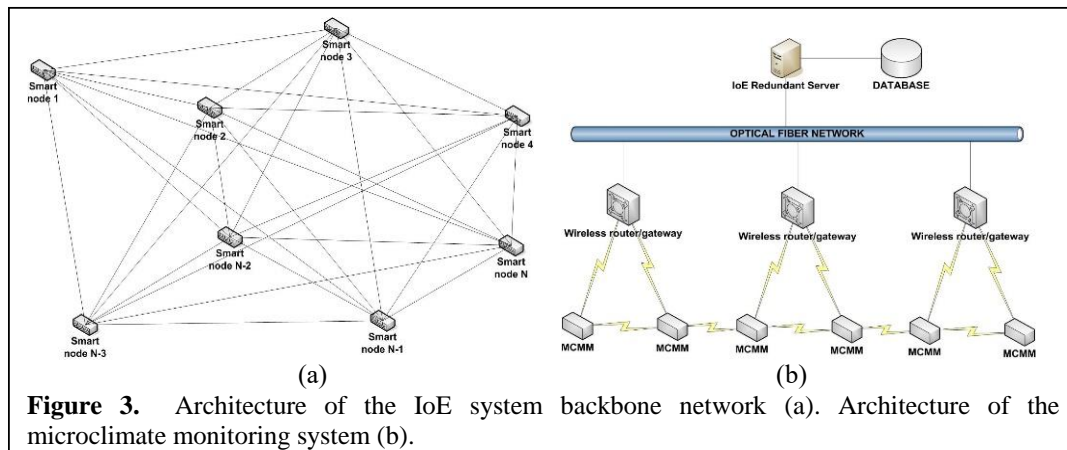
The system is characterized by a high modularity that allows for the addition at any time of any device, components, system etc. which requests to be integrated in the IoE system. The ITSF is designed to be a general system usable by most of organizations that can also plan for the presence of external 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.

A proper 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 facilities 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 allows the system to consider the mobile terminals as 'IoE objects' to reach the specific desired objectives of the considered organization. Thanks to the app, it is possible to position people using both GPS system of mobile terminals and the Wi-Fi positioning ability of the system (which can work properly even in underground environments where the GPS signal is shielded or weak). 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 ITSF is equipped with all the countermeasures necessary to prevent cyber-attacks, using firewall / intrusion detection system / anti-virus devices properly installed plus other prevention/protection countermeasures.

### 3. Design and Development of IMMSSM and IoE- ITSF System

Different actions have been carried out and are still going on both sequentially and in parallel, as a function of the available resources, always considering the final goal. Thus, a set of preliminary and essential series of multi-disciplinary activities formulated as set up of the IMMSSM and subsystems of the IoE technological system are considered [19]. Due to multi-disciplinary work that have been done and that is going on, an international group started working locally and remotely.

First of all, the introductory activities required to set up the IMMSSM have started, included the other actions necessary to study and design the Site Management System (SMS), for the specific site, based on IoE (SMS-IoE), as well as a new communication network which is essential to warrant that all the information required for the planned IoE services could be supported with the necessary level of security, safety, reliability and resilience, granting the required confidentiality, availability and integrity. From this point of view, a proper Genetic Algorithm 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 (Fig. 3a) to ensure a reduction of final costs and an elevated level of reliability and resilience of the system itself, considering the typical artefacts and restrictions of an inimitable cultural heritage site such as the considered one [20].



Due to the need of acquiring all the necessary information to be shared locally and remotely, a proper integrated survey of the Papal Basilica and of the Tomb has been done, which represents the purpose of this paper [21, 22]. This is aimed at obtaining also a 3D model of it that is going to be rendered into a Building Information Modelling (BIM) and to utilize a flexible tool for all the needed activities, including safety and security management [23]. This action is fundamental due to the presence of strong architectural restrictions, which involves taking care in the installation of wires and devices. Further details about integrated survey are illustrated in the following.

At the same time, a proper study and analysis regarding human factor was done and it is still ongoing. It regards the psychological aspects of the ordinary signalling and all the IoE services provided both to visitors and to personnel normally present for site management, including the Friar's community. It is aimed at improving the value and the effectiveness of the IoE services themselves and of those inside the site. These activities require the use of suitable tools for opinion mining of social networks to collect feedback from visitors on perceived safety/security versus real safety/security [18, 24].

Another parallel activity is related to an experimental microclimate monitoring system (MCMS) of the Papal Basilica, based on apt microclimate monitoring modules (MCMM), has been studied and realized and its architecture is shown in Fig. 3b. The MCMMS are aimed at controlling the microclimate parameters to avoid of reaching critical conditions which could trigger harmful processes of the unique frescos of the Basilica [25].



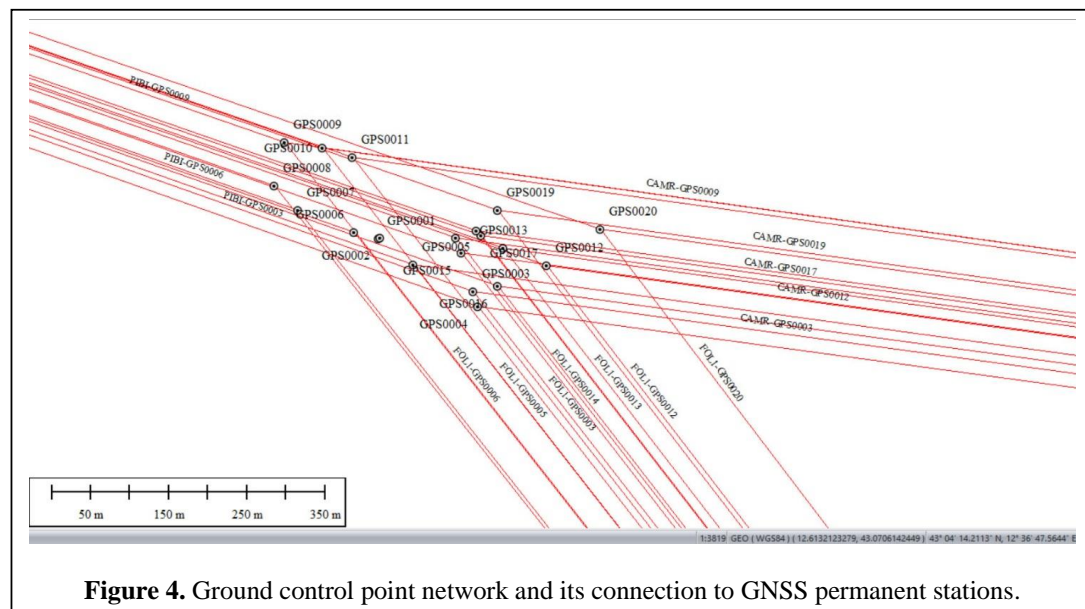
Other activities are dedicated to new and suitable IoT/IoE services for the considered site (such as people counting subsystem), including Augmented Reality (AR) and Virtual Reality (VR) intended at improving the visiting experience of the visitors; biometric solutions for the considered site, with particular 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, security analytics for Big Data infrastructure, machine learning techniques for the site etc., with the purposes of attainment, step by step and with the contribute of all the people and subjects that are working on it, the desired goals.

#### 4. The integrated survey

Different actions have been carried out and are still going on both sequentially and in parallel, as a function of the available resources, always considering the final goal. Thus, a set of preliminary and essential series of oblique photogrammetry, GNSS network and terrestrial laser scanners have been used to reconstruct a geometrical accurate three-dimensional model of the Papal Basilica and the Sacred Convent of St. Francis in Assisi, Italy. High accurate methodologies were studied and applied to this specific survey due both to the importance of the specific site and to the relevance of the structure for seismic damage prevention as it's widely discussed in literature [26, 30].

In planning the survey, we considered the best technique to model this historical monument. We focused our attention on laser scanning and close-range photogrammetry surveying two of the most diffused techniques for these specific surveys [31, 34] and then we planned the operations to execute the necessary measurements in the shortest time with the needed accuracy.

Specifically, the laser scanner survey has been realized for the indoor part of the 'basilica' (crypt or tomb, lower and upper basilica) and photogrammetry survey for the external part of the basilica itself. The laser scanning surveying needed the integration of 'classic' measurements techniques to georeference all the single scanning acquisitions in a single local reference system.



**Figure 4.** Ground control point network and its connection to GNSS permanent stations.

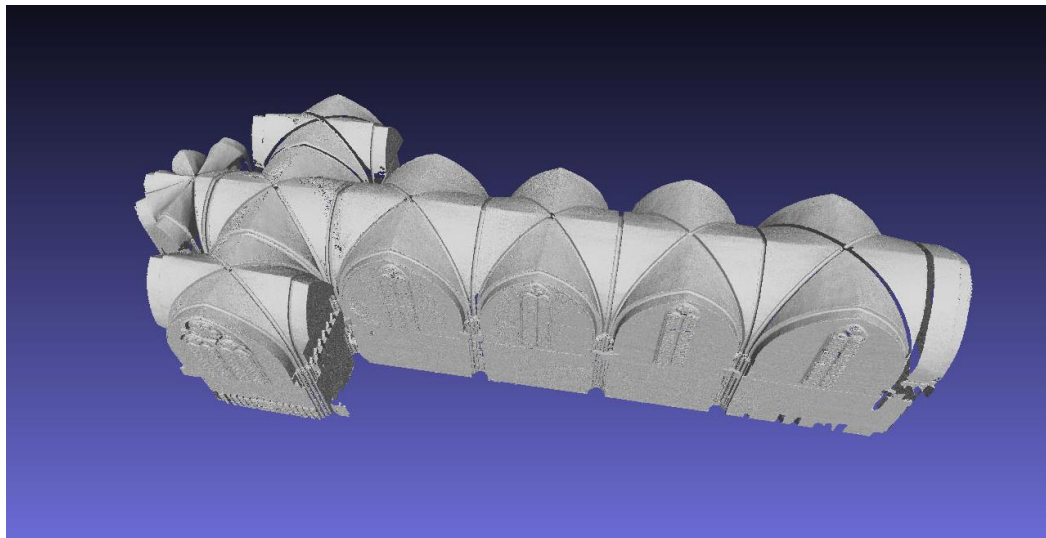
The surveying operations required, primarily, the realization of a GNSS reference network for the external part. This network has subsequently been connected to the indoor part of the basilica with a classical transverse survey so to be the base for the following measurements of detail elements.

Considering the required positional accuracy, the stop and go kinematic survey technique and post processing modalities were used referring to three permanent stations (Foligno, Camerino, Perugia) managed by Umbria Regional administration (Fig.4).

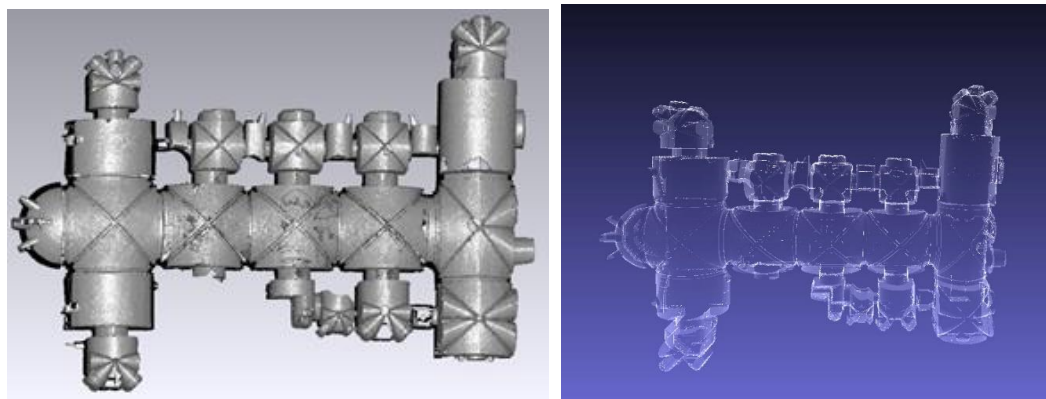
The preventive choice of the survey points has been realized using a simplified basilica model obtained by earlier surveys.

The topographic measurements have been performed with a total station Leica TPS 1201 and a GNSS receiver Leica GS12, while the adjustment has been made in STARNET and LGO environment.

Once defined the station and target positions, the laser acquisitions were performed considering that from every single station a suitable overlap with the following acquisitions was needed. As scanning parameters, a grid size of 1 cm and a mean distance of 20 meters were chosen considering the average size of the rooms. The scanning processing has been performed with different packages. A first process of alignment based on the recognition of the control points, the reflecting targets and the natural GCP has been performed using 'Cyclone 9.1.4'. The data processing has been separately processed for each level. The remaining processing were performed using Geomagic 2017, Meshlab 2016 and ICV packages (Figs.5, 6, 7).



**Figure 5.** 3D model of the upper Basilica



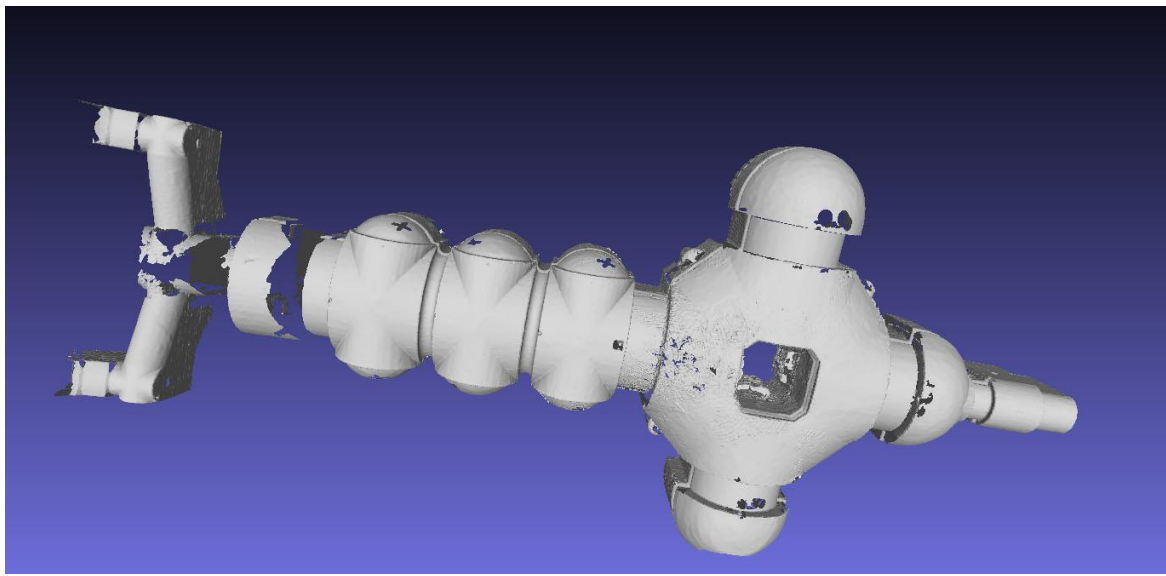
**Figure 6.** 3D models of the lower Basilica

The external part of the basilica has been acquired from aerial photogrammetric images techniques widely diffused in the recent years [35, 39]. The flight was specifically planned for this survey and it was performed by a single-engine Socata TB10, a light aircraft of the General Aviation. For the photographic images a digital SLR Nikon D5500 resolution, with 24.2 Megapixel with an ultra-fast autofocus system and dual-mode detection both of contrast and phase, was used. It has been used a photographic zoom Nikon 18-70 mm, using a fixed focal length of 70 mm for all the photos and with



ISO values fixed to 1600, kept low compared to the maximum of ISO 25600 available to minimize electronic noise.

The availability of a high sensitivity and resolution of the sensor, a fast autofocus system (to obtain every time sharpened and in focus images), a professional optics (very bright and with low chromatic and optical aberrations), an SD (Secure Digital) storage class 10 ultra (SDXC ultra-fast recording of images even in bursts at full resolution and in RAW format without loss of quality) ensured a secure



**Figure 7.** 3D model of the tomb or crypt

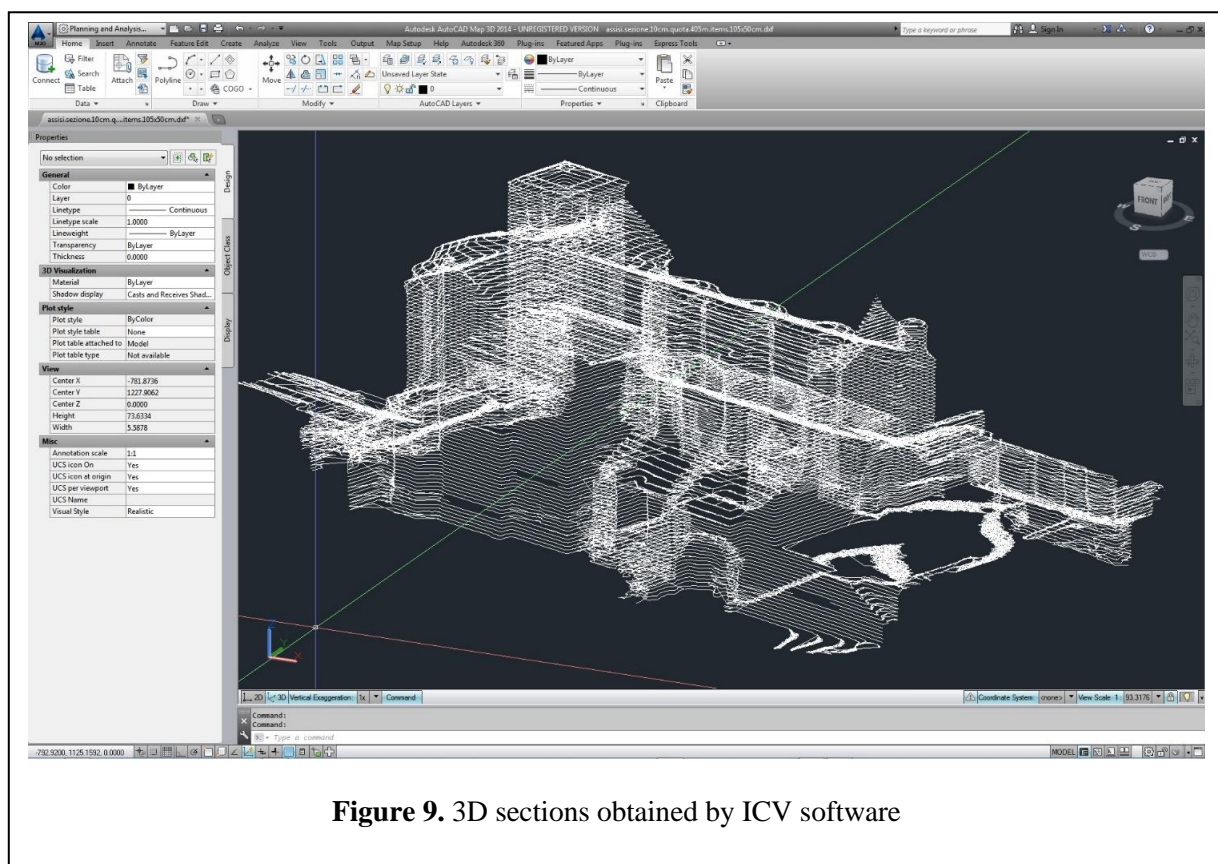


**Figure 8.** Cloud points obtained by aero photogrammetry

acquisition, minimizing the number of unusable photos. The images were acquired with aperture priority mode with values between f11 and f14, ensuring exposure times between 1/1500 and 1/2500 of a second or so, more than enough to avoid the occurrence of the unwanted image blurring.

In order of an easier and more prompt flight planning it was performed a proper FlightPlan software, developed and implemented by some of the authors. In addition to the paper-based information (aeronautical charts and flight logs) the pilot used also an electronic knee pad useful to constantly monitoring the aircraft's position, to improve the situational awareness and, above all, to quickly schedule any diversions in case of aircraft critical failure or emergency situations.

The photogrammetric point cloud was extracted in Agisoft PhotoScan 1.3.5 (Fig. 8), which provides photogrammetric restitution by mean of image processing and SfM (Structure from Motion) techniques. The high number of photo used (over 300), the high resolution and quality of the same and the high overlap of the images allowed to obtain a very detailed and dense point cloud (over 36 million of points). Considering that the scale of the photogrammetric model obtained was arbitrary, for georeferencing the point cloud a fine registration tools implemented in the ICV software was used. The ICV is a software developed by some of the authors [40] that allows also to easily obtain 3D



**Figure 9.** 3D sections obtained by ICV software

models and sections (Fig. 9).

## 5. Conclusions

The integrated survey for reconstruction of the Papal Basilica and the Sacred Convent of Saint Francis in Assisi in Italy has been presented. It is a still going on activity, due to the extension of the considered place. It has demonstrated to be a powerful tool to obtain all the necessary information to start to set up the considered Integrated Multidisciplinary Model for Security and Safety Management (IMMSSM) for the specific context, using a multidisciplinary approach, and the related IoE based

technological system which also allows to consider other key features such as energy management, maintenance management and a plenty of other aspects that must be managed in an efficient way.

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