THE DOCUMENTATION OF CULTURAL HERITAGE SITES IN CYPRUS USING INTEGRATED TECHNIQUES: THE CASE STUDY OF THE CHURCH OF AGIOS ATHANASIOS AND KYRILLOS

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ABSTRACT

Rapid technological development, as well as the great interest in the three-dimensional (3D) digitization of cultural heritage had resulted in the research project "Ecclesiastical Cultural Heritage Digitization Pilots for the Churches of Cyprus and Crete." The main objective is to document churches using a variety of non-invasive techniques in order to generate 3D models of the church for the management and promotion of cultural heritage sites, such as churches. In this paper, the integration of various technologies was used to document the 17th century Church of Agios Athanasios and Kyrillos in Agios Athansios in Cyprus. Technologies such as spectroscopy, laser scanning, multispectral and RGB imaging and photogrammetry were used to obtain a high-quality 3D-metric model for documentation. The implemented techniques on the 3D-models assist in qualifying pathologies in the cultural heritage site. Through the use of spectroscopy and multispectral imaging, the authors attempt to qualify the pathologies at church using a proposed Lithology Condition Index (LCI). The methodology used in this study was developed within the framework of the EXCELSIOR project.

Keywords: Cultural Heritage, multispectral, spectroscopy, laser scanner, photogrammetry, ecclesiastical monuments

1. INTRODUCTION

Reliable documentation is essential for proper management and preservation of cultural heritage sites. However, there are several factors that affect the condition of cultural heritage sites. The most common physical factors resulting in the deterioration of cultural heritage sites are moisture, erosion and pollution significantly affects the deterioration of as it results in the gradual decomposition of their construction materials [1]. Digital techniques can provide data on cultural heritage sites to enhance understanding of their changes over time [2]. In this paper, four different technologies will be integrated in order to create a 3D model of a church by using spectroscopy, laser scanning, multispectral and RGB imaging and photogrammetry. The combination of the technologies will provide a 3D model to document and identify cultural heritage pathologies.

In the field of heritage preservation, multispectral imaging is a suitable technique due to its non-destructive nature and its versatility. The combination of multispectral imaging and spectroscopy provides the capability to analyse the pathology of the building by using a variety of different geomatic sensors. These sensors collect both spatial and spectral information for a given scenario on a specific spectral range, in order to use the spectral properties of the radiation reflected by the surface of interest to analyze the pathology of the materials. Multispectral imaging is a significant method for documenting cultural heritage as it integrates data acquired by various non-evasive technologies, such as laser scanning, spectroscopy and photogrammetry to identify any damage on cultural heritage sites [3]. The condition of cultural heritage sites can be monitored and analyzed using remote sensing/electromagnetic sensors, based on the acquisition of spectral reflectance at different wavelength ranges [4].

Laser scanners are increasingly being used for cultural heritage documentation due to their high data acquisition rate, relatively high accuracy and high spatial data density, laser scanners are being used for such applications [5-7]. Laser scanners have the capacity of performing 3D surveys to document and quantify physical damages of cultural heritage. The laser scanners collect point clouds as a graphic representation of the object, obtained through the distances between the instrument and the object itself [8]. Photogrammetry, which uses both RGB and multispectral images, is an efficient and accurate technique for documentation of cultural heritage sites. Photogrammetry provides continuous covering of the object in a high-resolution context, with the result being a highly dense and textured 3D point cloud [9, 10]. Therefore, combining data from both a terrestrial laser scanner and from photogrammetry in increasingly being used to provide high accurate documentation of cultural heritage sites (11, 12, 8].

This paper provides the methodology that was used to document the 17th century Church of Agios Athanasios and Kyrillos. The church has significant moisture damage both outside and inside, which is also noticeably in the church interior, (Figure 1). The church was documented in 3D by using a laser scanner, as well as an RGB and a multispectral camera, whose images were then processed through SfM photogrammetry. As moss was beginning to grow on the side of the church, a spectroradiometer was used to acquire spectral signatures of the different areas of the church in order to identify the Lithology Condition Index (LCI), that is proposed in this paper.

Figure 1: Left: Moss resulting from moisture;
Right: Moisture damage to the corresponding area within the church

It is difficult to test the moisture content in the walls of cultural heritage buildings, as cultural heritage authorities permit limited intervention on the structure of the cultural heritage site. Often, a visual inspection of cultural heritage sites can detect pathological phenomena affecting the building due to visible symptoms. In the case of the church of Agios Athanasios and Kyrillos, a visual inspection showed that the walls are affected by moisture and, as a result, is affecting the frescoes in site the church. However, the cause of the moisture is difficult to identify.

The use of diagnosis techniques facilitates the ability to further examine the cultural heritage site, instead of relying only on visual inspections. The techniques described in this paper provide useful data to examine the pathology of the church. 3D multispectral techniques can provide all the qualitative parameters for the conservation and preservation of the cultural heritage site. Multispectral and infrared thermography data can be used for the diagnosis and inspection of cultural heritage sites, because they are powerful, fast and accurate tools that allows identification of the pathogens of the site, such as crack patterns, humidity, masonry, etc.

2. STUDY AREA AND METHODOLOGY

2.1 Study area

The study area was the Chapel of Agios Athanasios and Kyrillos in Agios Athanasios, in the Limassol District of Cyprus (figure 2). The vaulted type church was built of stone in the 17th century and seems to have been the community's church from the time it was built. The interior of the Chapel as is now fully illustrated. The “Platytera“ icon, also known as the Icon of Our Lady of the Sign, can be distinguished on a niche of the sanctuary as well as the Birth and Baptism at a part of the ceiling fixed by the end of the socket and the first arch. The church was refurbished in 1995 after its declaration to a monument by the Antiquities Department of Cyprus.

The church is currently being documented within the Ecclesiastical Cultural Heritage Digitization Pilots for the Churches of Cyprus and Crete.” During the documentation, it was evident that there is a high level of moisture on the ground, to the extent of having moss growing below the exterior stone wall of the church, which has also resulted in significant damage to the frescos. The presence of moss is significant, as they are more likely to grow on rough, porous surfaces such as sandstone, since the surface roughness of the stone and its moisture retention provide an ideal area for growth [13]. The presence of moss keeps the stone in a persistently wet state, which exacerbates stone decay and can cause pitting.

Figure 2: Church of Agios Athanasios and Kyrillos in Agios Athanasios
(Photo: Library of the Cyprus University of Technology)

2.2 Methodology

The methodology developed for the documentation of the Church began with a survey of the Church of Agios Athanasios and Kyrillos, including the placement of ground control points (GCPs) inside and outside of the church. The GCPs were used to achieve centimeter accuracy of the model, in order to geo-reference the 3D models, so that they can be overlayed and provide a detailed model of the church using the point clouds generated from RGB, multispectral and laser scanning. A laser scanner was used to document the church in the interior and exterior in order to create a complete point cloud of the entire building. The laser scanner point cloud assisted in the geo-referencing of the RGB and multispectral point cloud models. Following, the church was photographed using a hand-held RGB Canon M5 camera and with a multispectral Canon SH260 camera. Following, Structure for Motion (SfM) photogrammetry software was used to generate a point cloud of the church from the RGB and multispectral images using the GCPs to geo-reference the models. As well, spectral signatures of the church walls were taken with an SVC 1024 spectroradiometer and were used to analyse the multispectral point cloud model and to apply the newly developed Lithology Condition Index (LCI), which identified the areas of wall pathology of the church. Finally, the point cloud models were integrated, thereby providing an accurate documentation of the church with the overlay wall pathology. The complete methodology is featured in figure 3.

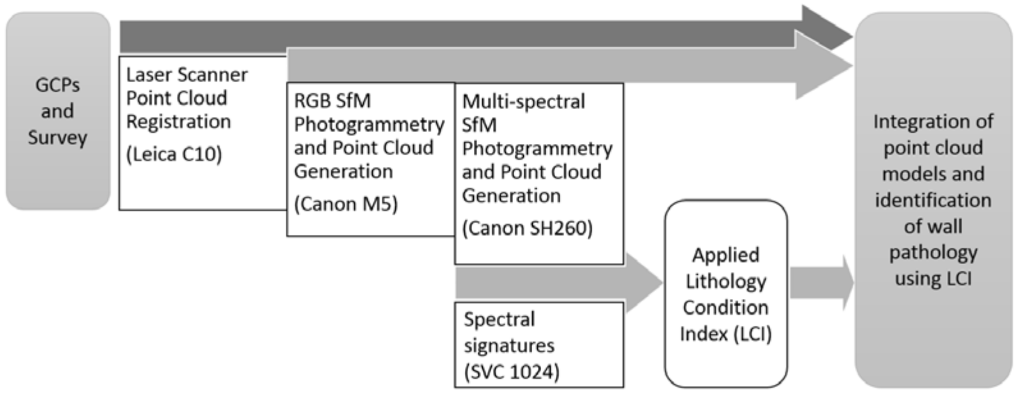

Figure 3: Methodology for identifying LCI

2.3 Laser Scanning

The 3D laser scanner Leica Scan Station C10 was used to document the Church. The specific laser scanner has a maximum scan rate of 50000 points per second, while the accuracy is ±6mm in position (X,Y,Z) at a distance up to 50m. The laser beam diameter is ±7mm, while the field of view of the Scan Station is 360º × 270º. Moreover, the laser allows acquiring the reflected beam intensity and RGB colours [14, 15]. For scan data collection of the church, the resolution of the scanner was set to medium resolution. For the detail scan collection of the fresco and the icons in the church, the laser accuracy was set in the highest accuracy. The grid resolution was 10 mm in a 10 m distance. Data processing was performed following the collection of data. After the point clouds where collected, the first step of the processing involves the cleaning of the data to remove removed any noise which was capture during the laser scanning procedure. Following, the registration procedure of point clouds was performed using the scan targets. After the registration the XYZ coordinates of all scan points, they can be transformed into a common coordinate system. The registration of the point clouds was achieved with an accuracy of less than 1cm. After the point clouds where cleaned, the following step was the creation of the surface and the creation of realistic visualizations. The Church 3D model point cloud in Figure 4 was generated by a Leica C10 laser scanner.

Figure 4: Church 3D model point cloud generated by leica C10 laser scanner

2.4 Photogrammetry

Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images [16-18]. The area should have fixed ground control points (GCPs) for geo-referencing in order to produce a photogrammetric ortho-image and point cloud 3D model of the area of interest and for comparison over temporal intervals [17]. Photogrammetry is a precise 3D measurement technique based on the triangulation of several high-quality images that allow for the collection of semantic and spatial data of a building or object to be accelerated. In this paper, a Canon M5 RGB camera was utilized for the photogrammetry process. The main outputs of photogrammetric surveys are raw images, ortho-photos, DEM and 3D points clouds created from stitching and processing hundreds or thousands of images. Several widely used commercial software are available in order to obtain 3D reconstructions of buildings from RGB images. These tools, usually based on the Structure from Motion (SfM) approach, enables 3D reconstruction with camera self-calibration. The software implements image orientation and mesh generation through SfM and dense multi-view stereo-matching algorithms [19]. The first step in the program's procedure is SFM, which is a valuable tool for generating good quality meshes from images in a semi-automatic way. At this stage the software analyses the data-set, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used in order to align the images, including building a sparse point cloud [20]. Figure 5 features the 3D model point cloud generated by RGB images.

Figure 5: Church 3D model point cloud generated by RGB images

2.5 Multispectral imaging

Multispectral imaging is useful in documenting cultural heritage sites due to their portability, cost savings, the short data acquisition time required, and their level of detail among others. it provides higher spectral resolution collecting several thousand contiguous, narrow bands, thus allowing for the reconstruction of almost continuous reflectance spectrum It combines imaging and spectroscopy in order to analyse materials using geomatic sensors. These sensors provide information regarding the spectral properties of the area of interest. Multispectral imaging is a versatile tool for documenting cultural heritage, as it can generate 3D textured models from images acquired at different regions of the spectrum, provide images and orthoimages and create mapping products for quantitative and qualitative analysis [1]. As a result, multispectral imaging can assess a variety of data, including possible chemical and physical pathologies, respectively. Multispectral cameras include sensors that use multi-lens systems with different filter combinations to acquire images simultaneously for its spectral ranges. However, they are very sensitive to changes in lighting conditions, are affected by shadows and they should require some image corrections. It is also important to choose a correct configuration of their spectral bands in order to cover the spectral behavior of the pathology of the material that is being analyzed. In this paper, the Canon SH260 was used for multispectral imaging. Figure 6 features a 3D model point cloud of the church that was generated after the use of the LCI using the blue and near infrared channels from the multi spectral camera.

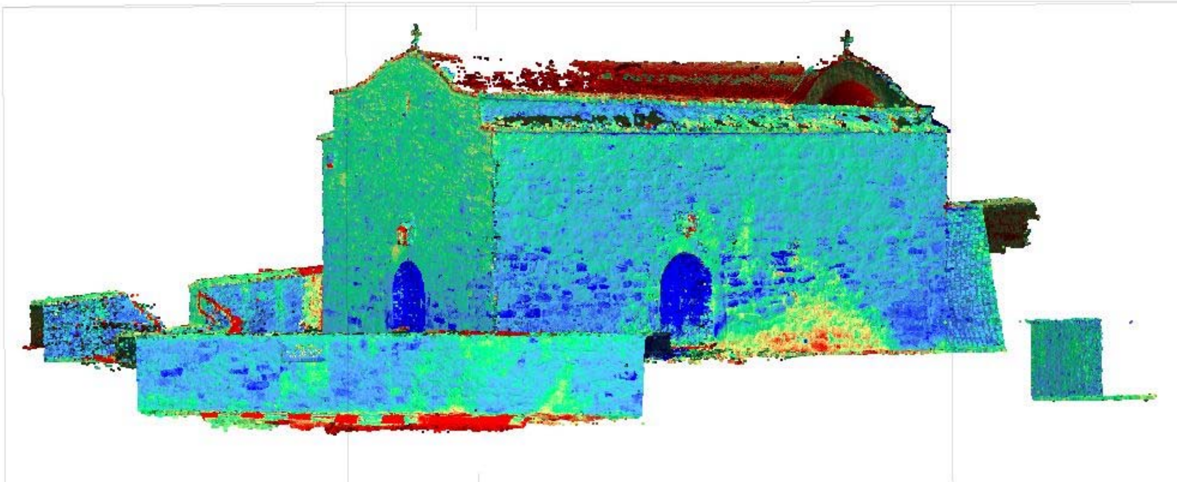

Figure 6: Church 3D model point cloud generated after the use of the LCI using the blue and near infrared channels from the multi spectral camera

2.6 Spectroscopy

Spectroscopy provides the ability to derive conclusions about the spectral reflectance of a material. This is accomplished by measuring the energy reflected, absorbed and transmitted by an object based on wavelength, material and texture. The measurement of the spectral bands required to identify a pathogen depends on the specific spectral signature of the object, which varies greatly as a result of physical properties. Therefore, spectroscopy can be used to acquire spectral signatures of various aspects of the same object. As a result, wavelength configuration can be used for successful pathology assessments and material characterizations of cultural heritage sites. In this study, the SVC 1024 spectroradiometer was used to acquire spectral signatures in different locations and conditions of the walls of the church.

3. RESULTS

After applying the methodology, a 3D model was generated that integrated all the point clouds, including the laser scanner and the photogrammetry from the RGB and the multispectral camera. This was necessary in order to create a complete 3D model of the entire church. As the images were taken at ground level, the combination of all three methods provided a complete model of the church.

In order to identify the behavior of the stone wall within various conditions, such as stone with moss, stone with pitting, stone without moss, a SVC 1024 spectroradiometer was used to obtain spectral signatures (400–2500 nm) from the wall to study the different areas. The spectral signatures obtained (figure 5) indicated a low reflectance value at the blue band (400-500 nm) and a high reflectance value at the near infrared band (700–800 nm). The multispectral camera Canon SH260 uses three bands with blue (400-500 nm), green (500-600 nm) and near infrared (680–800 nm). Since the spectral signatures of the walls showed a low reflectance at the blue channel and high reflectance at the near infrared channel, only the blue (400-500 nm) and near infrared (680-800 nm) band were used in order to create a 3D point cloud using the images from the multispectral camera.

Using the minimum values from the blue channel and the maximum values from the near-infrared channel, we applied the Lithology Condition Index (LCI) created for the study documented in this paper by subtracting the maximum value from the near infrared channel to the minimum value of the blue channel and divide it by the addition of the two channels (equation 1).

$$LCI = Lmax - Lmin \,/\, Lmax + Lmin \qquad (1)$$

The spectral peak from the blue channel from the SH260 camera was at 470 nm and from the near infrared channel was at 720 nm, as shown in figure 7. Therefore, the following equation was applied to the 3D model (equation 2)

$$LCI = E_{nir} - E_{blue} / E_{nir} + E_{blue} \qquad (2)$$

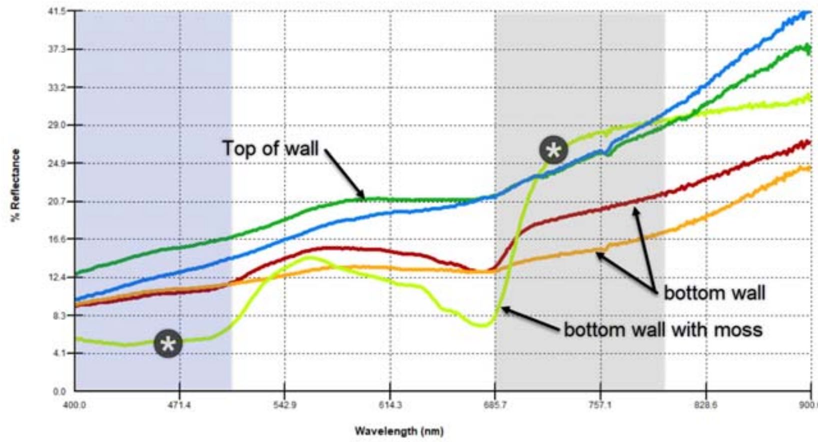

Figure 7: Spectral signatures of the church

Once the LCI equation was applied to the 3D point cloud model of the blue and near infrared channel taken from the multispectral camera, it was evident that there were which were indicative of a high level of moisture within the masonry wall. This is evident in Figure 1, where the high moisture level on the outside of the church caused damage to the frescoes on the corresponding inside part of the church.

The LCI equation using multispectral imaging showed high levels of moisture (indicated in red) in the masonry at the north and south areas of the church, as shown in figure 8 below.

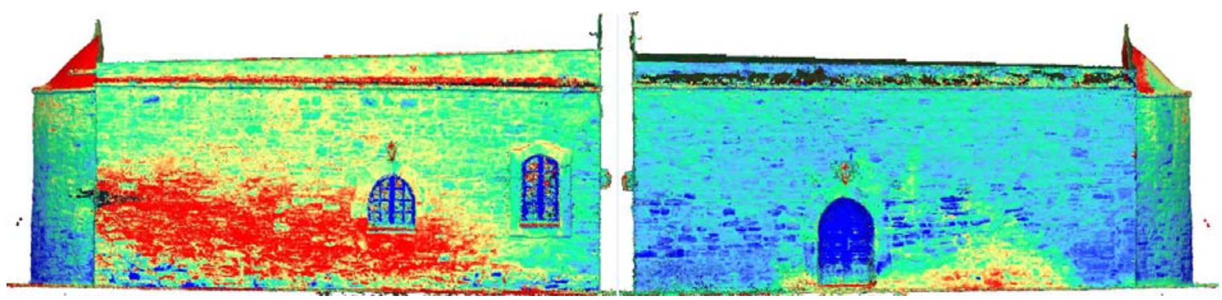

Figure 8: Left: North view of church; Right: South view of the church
LCI using Multi-spectral showing moisture in red color

Figure 9 features the aerial image of the church with geo-reference GCPs while Figure 10 features the church from two different angles. The images were generated by combining the results of the laser scanner and multispectral images processed using photogrammetry. The legend at the left side of the image indicates the amount of moisture present on the church grounds and the walls of the church. As is evident, the red sectors of the image indicate higher moisture levels.

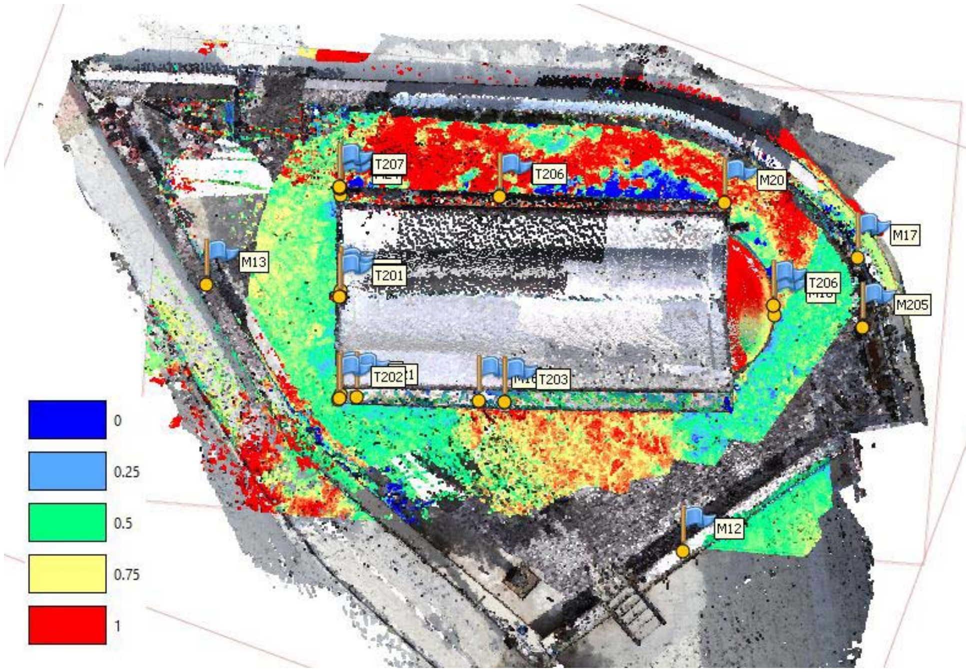

Figure 9: Ortho-image site plan of the Church using a combination of laser scanner, RGB and multispectral images processed using photogrammetry

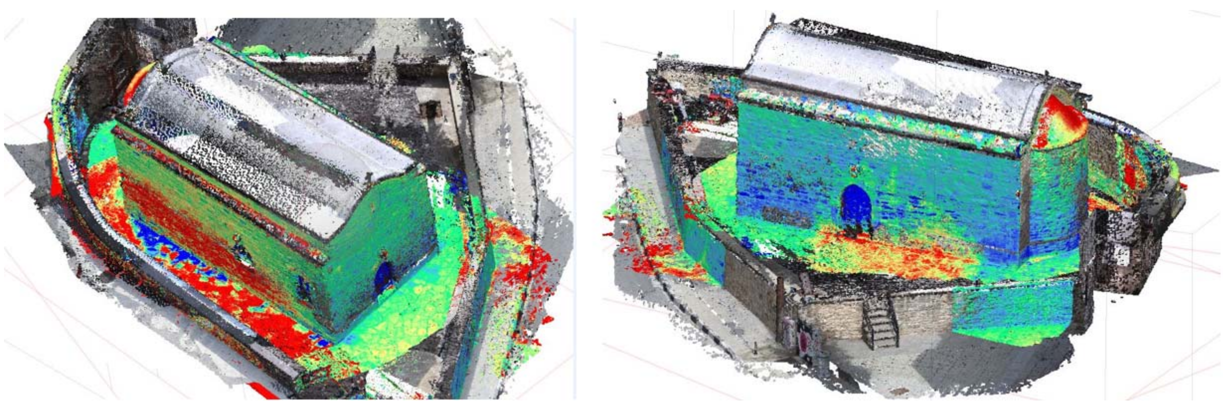

Figure 10: Left: Multispectral image of the level of moisture present around the church, as indicated in red

Similar techniques were used by Del Pozo [1], where the presence of moisture in a structure was identified through the analysis and processing of multispectral data from multiple sensors. The results of this methodology can be used for early detection of moisture in order to minimize the degradation of cultural heritage sites. Since each material has a unique reflectance behavior depending of the wavelength, the presence of pathologies on walls, such as moisture that can generate moss is likely to be successfully detected by analyzing the reflected visible and near infrared radiation from the wall reflectance, which indicate that the pathologies are derived primarily from moisture. The results from the LCI index show that the moisture that is collected on the ground outside of the church is resulting in moisture being absorbed by the wall and penetrating the church walls in the interior of the church and destroying the frescos. In order to terminate this damage, an extensive restoration needs to be conducted in order to remove and stop the moisture by penetrating the church walls.

4. CONCLUSIONS

This paper examined how integrating various technologies, such as laser scanning, photogrammetry and multispectral imaging can be used to create accurate 3D models of cultural heritage sites. It also introduced the Lithology Condition Index (LCI), which was developed as a method to identify moisture within materials, such as stone walls.

The results of this study clearly indicate that multispectral imaging is a successful technique for detecting moisture in affected areas. The spectral signatures of the wall found that the most suitable spectral range for moisture detection is the near infrared. However, this configuration is not ideal to discriminate materials and other pathologies such as moisture, degradation and decomposition, so it should be combined with other sensors in order to obtain more comprehensive results. In relation with the most common pathology of cultural heritage, the moisture content, it can be drawn that it is well characterised in the near to medium infrared range [1].

Using multispectral sensors, it is important to choose the correct configuration of spectral bands in order to acquire the spectral behavior of the pathology/ material to be analysed. The configuration of the multispectral camera used in this study (SH260 400-800 nm) was ideal to analyse biological colonization, such as mosses, lichens and vegetation in cultural heritage elements. The integrated 3D model was able to differentiate the main pathology of the walls and qualify the moisture present on the ground and the church wall.

Future work can include using a thermal infrared camera in order to quantify and measure the amount of moisture in different parts of the structure. The measurements from the thermal infrared camera can then be incorporated into the present methodology to quantify and provide a more detailed documentation of a cultural heritage sites. Detailed documentation can provide vital information to stakeholders and decision makers regarding conservation and preservation efforts.

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