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Geomatics as a knowledge base propaedeutic to the restoration of an extended *fresco* wall

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***Abstract* – In the project, carried out by the Geomatics group of the DICAM Department from the University of Bologna, it is discussed the integration of different sensors as an application to the field of Cultural Heritage. The fresco painting examined dates back to the beginning of the XVII century, it is found in the San Martino theatre hall, in the city centre of Bologna. Terrestrial Laser Scanner (TLS), Photogrammetry and Thermal Analysis were employed as support for the analysis of the damaged fresco, and their integration, upon calibration, allowed to obtain a detailed representation and mapping of the fresco and its decay. In addition, it is now carried out a further research considering the role of Intensity of the TLS data, which could provide additional information about the conservation state of the painting's surface.**

I. INTRODUCTION

In the last decades, the application of Geomatics to the field of Cultural Heritage hass experienced an increasing demand of innovative methodologies to collect, process, validate, and exchange digital information; one of the most interesting areas is the restoration and conservation.
Embracing and supporting restoration and conservation policies means becoming aware of the cultural and artistic identity of an artefact of a city, territory and encouraging its memory. The application of innovative techniques to the field of restoration of cultural heritage is not only interesting for the people working in this sector, but represent a fundamental tool to improve the outcomes of the intervention and valorise the artwork, which in turn can catch interest from the public. The different phases of a restoration or conservation intervention can be assisted by techniques capable of providing an accurate documentation of the artwork. The possibility of obtaining three-dimensional reconstructions, thanks to digital breakthroughs made possible by photogrammetry, laser scanning and other geomatic techniques, has increased richness of the surveys and the gathered information is characterized by an overall higher level of precision in respect to those common 2D techniques that were applied for more than a century (like drawing, photographs, tracing) [1, 2, 3].
In this context, the paper shows an experience carried out by the Geomatics group from the DICAM Department of the University of Bologna on an extended fresco wall in the city of Bologna.
The aim of the research was the integration of geomatic techniques as photogrammetry, laser scanner and thermal analysis so to provide a very detailed survey and products where the different metric and thermal information, in turn possibly linked to moisture, are given in the same reference system. In addition, a study is in progress with the aim to consider the additional parameter of Intensity of the TLS data to retrieve information concerning the degradation of the fresco.
Such type of work is important as it can provide *a priori* information about the degradation state of an artwork, knowing exactly the position of its damaged areas. Also, these techniques do not require a direct contact with the artwork, being totally non-destructive. This is a key factor in Cultural Heritage Science, as the object under investigation is not subjected to any alteration or modification.
All the collected data constitute a 3D multi-sensor archive of the current state of the fresco and a knowledge base fundamental for all the future restoration interventions.

A. The fresco in the Carmelite library of San Martino Maggiore, 1629, Bologna

The library of the Carmelite convent, which extends over the chapel which has long been used as a sacristy, was built between 1625-1629 by the architect Giovanni Battista Falcetti, repeatedly involved in contemporary city sites, both diocesan and religious. In the back wall there is the largest fresco in Bologna, measuring 104 square meters (13 × 8 m).
The fresco was painted by Giorgio Massari and Girolamo

Curti in 1629 [4]. The painting depicts a crowd of people listening to the lesson of the French Pier Tommaso, Pierre de Salignac de Thomas. This Carmelite was the founder of the Theological Study of Bologna and was among one of the first teachers (1364). He is represented speaking from his chair located in the centre of a loggia marked by high Doric columns and completed by a coffered ceiling, while airy serliane connect it to the porticoed courtyard that opens in the background. Girolamo Curti, known as Dentone, structured the illusionary architecture as on a stage, enriching it with proscenium, diagonal scenes, backdrop. A spatiality effect is evident: we see listeners sitting on the ground or on the step in the foreground, behind them some are listening, others speaking and gesticulating, in such a way that their disposition helps suggest depth to the scene.

Fig. 1: The fresco by G. Massari and G. Curti (http://www.centrosanmartino.it)

The over sixty figures are the work of the ingenious Lucio Massari (1569-1633), scholar by Bartolomeo Passarotti and then by Ludovico Carracci, who was inserted by them in the *Accademia degli Incamminati* and then became a member of the *Compagnia dei Pittori*. The painter, even on the occasion of the intervention in the library, adopts a balanced, archaic, severe language, with the pathos of post-conciliar painting, much practiced in Bologna and urged by cardinal Gabriele Paleotti.

Thanks to the scaffolding, an indispensable tool necessary for painters to reach the upper parts of the surface intended to accommodate the realization of the subject, the work began in the upper level of the wall and the different days ("giornata") of the fresco were marked over the brick floor of the library.

The hall where this fresco is found underwent many transformations during the centuries, adapting to different uses (library, cinema, theatre, university classroom and theatre again). After the second world war, when the space was turned into a cinema, some holes were drilled on top of the fresco for the projection, and the painting was covered by panels. All these interventions, together with seepages of acidic rainwater in correspondence to a drainpipe, have severely damaged the valuable artwork, which now is seen in an unfortunate state of conservation. In particular, the infiltered water from the top migrated through the wall, with consequent re-crystallization of the soluble salts during the evaporation phase.

In 2010, the fresco faced an intervention aimed at establishing the state of conservation and characterizing the materials as well. Several techniques have been employed: first of all a chemical-stratigraphic and mineralogic-petrographic diagnosis to characterize the plaster and define the ratio of binder/aggregate, the composition and the granulometry of the sand, so to identify the geographical and geological area of origin. In addition, the composition of the efflorescence, of the pigments and the binders, and the painting technique were defined [4].

B. Non-destructive techniques chosen for the mapping of the decay

The application of non-destructive digital surveying techniques, like terrestrial laser scanning (TLS) and photogrammetry, allows to record the position, dimensions, and shape of a Cultural Heritage item. The knowledge of such characteristics for an historical/archaeological/artistic work is a necessary part of every project that involves a restoration or conservation intervention, being a fundamental element for the documentation and analysis process [5, 6].

Thermal analysis, also being part of the non-destructive techniques, can provide information about the conservation state of the surface investigated, highlighting the presence of pathologies linked to thermal or hygro-thermal differences, which may be due to the material itself, construction techniques, or any modification occurred in time [7]. Walls humidity and water infiltration can cause the soluble salts to re-crystallize forming efflorescence, which indeed had been seen and chemically characterized in the study conducted in 2010. The integration between the thermal and the metric data with higher resolution is a valuable tool for an accurate mapping and representation of the decay of the fresco.

The information provided by a TLS consists of a 3D cloud of points representing the object's surface, where each of these points is characterized by the triplet of its position in the space (x, y, z) and by a value of intensity, which is related to the amplitude of the returned signal, *i.e.* the "amount" of signal received by the detector once that the radiation sent by the instrument is reflected off the object's surface. TLS can provide information useful from different perspectives. Most of the studies focus on the geometrical information provided; besides these data, the intensity value - at the TLS wavelength - can also be used as an additional source of information. Ideally it is desired a value which is independent on the incident angle and on the distances, but depends uniquely on the properties of the material being scanned. For diffuse surfaces, this value is the reflectance, being in the range [0, 1]. The properties that affect the surface and in turn the value of reflectance are physicochemical characteristics like roughness, colour and moisture [8, 9, 10]. The equation that links intensity and reflectance is given by (1) [11]:

$$Intensity = \rho_1 \cdot C_1 \cdot C_2 \qquad (1)$$

where ρ_1 is the reflectance of the material, C_1 is an unknown but constant parameter for a specific scanner, C_2 is a parameter that depends on the distance and on the incident angle whose reduced effects on the intensity value were studied [12].

These topics can be of interest for applications like the one described. Given the polychromatic surface of the painting, it is expected that, apart from the variations that could derive from changes in humidity or texture, the reflectance registered will vary also according to the colour. This study is in progress, in order to evaluate how the intensity from the TLS point cloud could provide information about the decay.

Another study in progress concerns the small deviations of the surface obtained by laser scanning with respect to a local best-fit plane, highlighting possible areas of detachment of the fresco.

II. MATERIALS AND METHODS

A. Instruments

The instruments employed for the survey are a 3D laser scanner Riegl VZ-400 coupled with a DSLR Nikon D90 camera, a thermo-camera Flir P620, a DSLR Canon Eos 5D MarkII camera provided with a full-frame 36x24 mm CMOS sensor and wide-angle lens of 24 mm. In the phases of calibration/co-registration, special targets realized in laboratory were used: 3x3 cm^2 gres porcelain tiles over which a reflective adhesive paper was set, with the centre of the tile being spotted by the intersection of two oblique lines, shown in Figure 2.

The thermal camera employed is provided with an infrared sensor with geometrical resolution of 640x480 pixels (0.3 Mpixels) and an optical sensor working in the visible range with geometrical resolution of 3.2 Mpixels. Other characteristics are: IFOV of 0.65 mrad, thermal sensitivity of 65 mK at 30°C, nominal focal length of 38 mm and a detector with 7.5 to 13 µm spectral range. The calibration of the thermal data is essential to identify an object in its exact position and to allow the integration between the thermal image and the optical one obtained by a photogrammetric survey or with highly detailed data of different nature, like a mesh from a TLS survey.

The chosen approach for the calibration, both of the thermal camera and of the visible one, is the bundle adjustment with field calibration, through which the internal unknown parameters and the camera orientation are estimated, using a set of points derived from a laser survey at high density. The calibration is so performed through measures carried out in situ, working on an overabundant number of control points defined by the targets, conveniently distributed, collimated from one or more positions. The goodness of the accuracy obtained is then estimated considering the pixel dimension.

B. The surveying phases of the fresco

The surveying and data processing steps consisted in:

1) Positioning of the targets over a calibration 3D grid on a wall;
2) Acquisition of this grid with the thermal camera;
3) Field-calibration of the thermal camera;
4) Acquisition of the visible images over a specific calibration grid;
5) Self-calibration of the visible camera;
6) Surveying by laser scanner of the painted wall;
7) Acquisition of photogrammetric and thermal images of the fresco;
8) Determination by TLS surveying of the coordinates of the markers put on the fresco and used as Control Points in images processing;
9) Processing of the laser survey and of the photogrammetric and thermal images of the fresco.

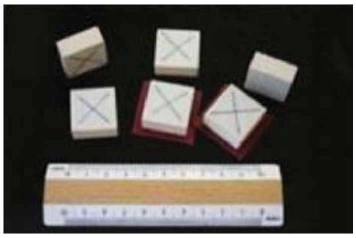

Fig. 2: Targets employed to create an ad-hoc grid for the calibration of the thermal camera and during the survey of the fresco

C. The self-calibration of the thermal camera

The porcelain targets (93 in total) were cooled before use, so to be perfectly visible in the thermal infrared, and then put on a lateral wall of the theatre, to create a grid to perform the optical calibration of the thermal camera. This choice was made in order to minimize the risk of damage to the fresco due to a large number of targets attached to it. Their images on the thermal camera resulted neat and well-identifiable, as shown in Figure 3. To be put on the wall, a double-faced adhesive tape was put behind the tiles, together with a paper adhesive strap so not to be in direct contact with the wall and being easily removed. In addition, a retro-reflective material was added on top of the tiles, allowing their identification also in the visible images. For this reason, these can be considered "multi-sensor" or thermal-laser-visible targets.

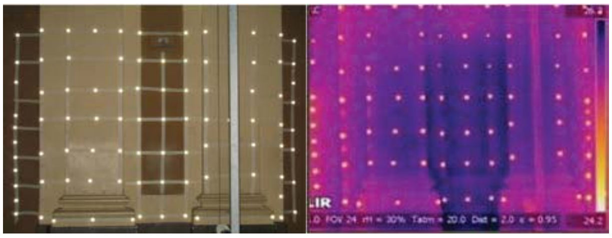

Fig. 3: 3D calibration grid seen in the visible (left) and in the thermal IR (right)

For the calibration of the thermal images over the calibration grid, 50 acquisitions were done by a distance of 8 m, of which 31 used for the internal orientation. The acquisitions were performed on this wall and on the fresco consecutively with the same instrumental conditions of focus, distance and avoiding turning on and off the camera so to not change the optical asset.

A self-calibration procedure was performed in Australis package with the method of bundle-adjustment, and the unknown optical interior parameters of the camera were found.

D. The TLS survey

35 multi-sensor ceramic tiles, like those shown in Figure 2, were put on the fresco, surveyed by the laser scanner, and used as Ground Control Points in the photogrammetric and thermal images processing.

The usual surveying steps were applied: 360° panorama acquisition, high resolution scanning of the reflectors useful as tiepoints in the scans registration, acquisition of the painted wall at the desired points spacing.

In order to survey the entire hall, 3 scan positions were chosen and from one of these, central and frontal with respect to the fresco, a detailed scan was performed with an angular interval of 0,03°, obtaining a spatial resolution of 2 mm from 10 m (Figure 4).

Coupled to the scanner, was set the digital DSLR camera Nikon D90 with a lens of 24mm, which immediately after scanning acquires the RGB images useful for colouring the point cloud.

Completed the acquisition phase, the data processing was performed with the RiSCAN PRO software provided by Riegl, employing the targets during the alignment phase, fusion and registration of the scans. The point cloud obtained consisted of about 30 million points. After the alignment and registration of the point clouds, the entire model obtained was roto-translated so to define a unique reference system for the laser and the photogrammetric survey, with the origin on the fresco plane and the z axis coming out of the plane. After a filtering phase a decimated Digital Surface Model (DSM) of 5 cm step was generated, reducing in this way the point cloud as a point every 5 cm, for a total of about 45000 points. The DSM was in the final stage employed for the construction of an orthophoto by photogrammetry of the painted wall.

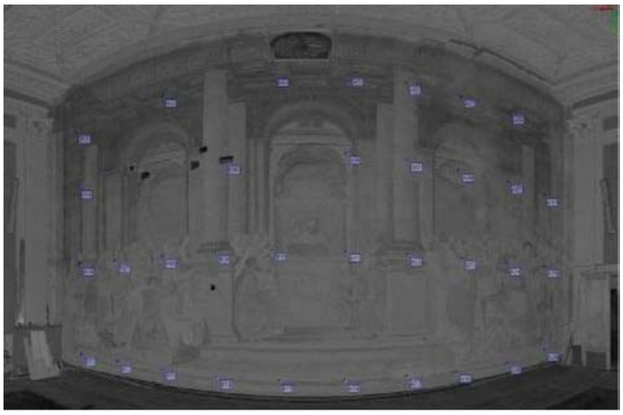

Fig. 4: Point cloud of the fresco obtained by the laser.

E. The photogrammetric and thermal surveys

The acquisitions of the wall by photogrammetry were performed with nadiral views from 8 different positions, covering all the wall, using a special tripod extended up to a height of 7 m from the ground. The obtained images were 24 (with a GSD of 1.3 mm) from a wall distance of 4,80 m, with a longitudinal covering of 20%, and with a baseline of 1.60 m, acquiring the photogrammetric block according to three vertical strips (up, medium, low), as shown in Figure 5.

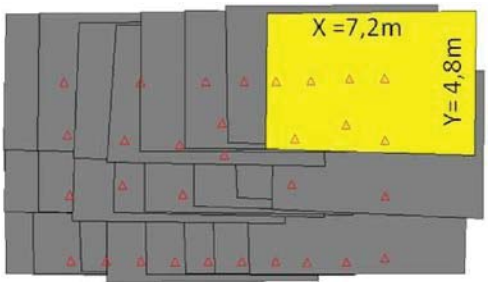

Fig. 5: Photogrammetric block, with highlighted the size of a single photogram.

The thermal survey concerned the right side of the fresco, because more subjected to degradation phenomena very well visible also by naked eye, recognized as salt efflorescence. The area, with dimension 6x8 m^2, was acquired from 3 different positions, with a distance of 8 m from the wall, employing a baseline of 1,30 m, again with three vertical strips (up, medium, low) capturing a total of 9 thermal images (with a GSD of 0.5 cm).

In addition, a thermal image covering the entire wall was acquired by a distance of 24 m, with the aim to derive a thermal rectified image of the entire fresco, shown in Figure 8.

It was not possible to perform, for all the images acquired in RGB, a radiometric correction through white balancing, employing systems like a colour-checker chart, because on the scene it was not present a homogeneous condition of illumination.

F. Digital Orthophoto

With the 3D data information, obtained from the laser derived point cloud, the DSM of the entire surface was produced, over which some first analyses were performed. Evaluating the values of the DSM it was possible to find a non-planarity of the painted surface, which presented a deviation of 4-5 cm from the vertical plane (Figure 6).

One of the products obtained by photogrammetry was the orthophoto shown in Figure 7, characterized by a nominal scale of 1:50 and a resolution of 2 mm.

Overlapping on this the rectified image produced by the thermal survey, it is possible to better understand the degradation condition over the fresco. The area where the effloresce is seen corresponds to a surface with decreased temperature (Figure 8).

According to these results, it is possible to imagine paying more attention towards those areas that appear colder, performing analysis of cyclic monitoring. Also, the intervention of restorers or conservators could provide additional help so to define the limit values of temperature and moisture, allowing the safeguard of the painting.

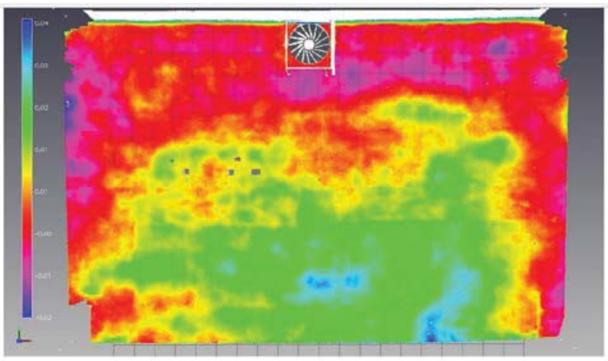

Fig. 6: Colour representation of the DSM obtained by the TLS survey, showing a variation along z going from -2 up to 5 cm.

G. The orthophoto-mosaic of the thermal images

The images of the thermal camera have been radiometrically homogenized in respect to a test image which was covering the area where the efflorescence is found, common to the 9 thermal images. The corrections of the remaining 8 thermograms were carried out considering the temperatures, read on the thermal images, of 6 common reference points, close to the targets of the central image and used as reference points, because these could be distinguished on the thermograms. For the six reference points considered, common to the 9 thermal images, ten Δt of temperature were calculated in respect to the value of temperature of the test image. The Δt values calculated were then summed to all the thermal images, in order to minimize the radiometric discontinuities among the images.

Fig. 7: Orthophoto of the fresco (original nominal scale 1:50, pixel resolution of 2 mm).

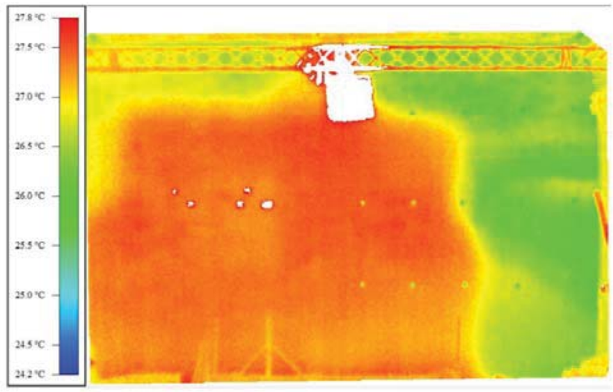

Fig. 8: Thermal rectified image of the painted wall acquired from a distance of 24 m.

Since in this case study the absolute temperature of the fresco was not taken into account, but rather anomalies or relative temperature differences have been considered, it was not believed necessary to carry out a real radiometric correction of the thermal images.

The obtained corrected thermograms were processed using the software LPS Erdas from Leica, with the aim to generate an oriented orthophoto-mosaic of the thermal images, later classified with the density slicing technique, which provides a straightforward information about the temperature.

Figure 9 shows the overlay between visible and thermal orthoimages.

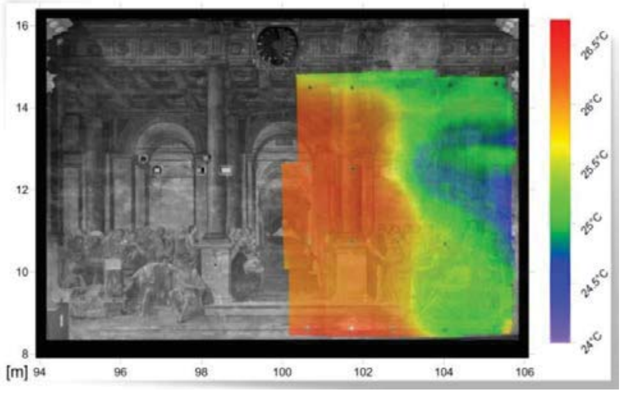

Fig. 9: Overlay of the visible and thermal orthophoto-mosaic, classified by density slicing, with indication of the temperature.

III. CONCLUSIONS

The work illustrated some preliminary activities to a restoration intervention, presenting an interesting case study and identifying the methodology to co-register the data acquired by two optical systems (visible and thermal), using as a support, and further data gathering device, a terrestrial laser scanning.

A survey performed with integrated techniques was able to provide important data for the mapping of the fresco and its damaged areas, which spatial extension confirmed the preliminary hypotheses especially in the top-right portion of the fresco. Working in this way, it is possible to carry out on the fresco operations of control and monitoring with survey systems which are non-destructive and non-invasive: the survey can be of support for a restoration intervention, as it highlights the areas that mostly need being cared of.

Further investigations are in progress to use the additional information provided by the intensity value contained in TLS cloud point, and to evaluate the smallest deviation of the painting area from the original plane surface.

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REFERENCES

[1] P. Grussenmeyer, E. Alby, P. Assali, V. Poitevin, J.-F. Hullo, E. Smigiel, “Accurate documentation in cultural heritage by merging TLS and high-resolution photogrammetric data”, Proc. of SPIE 8085, 808508, 2011.

[2] E. Stylianidis, F. Remondino, “3D Recording, Documentation and Management of Cultural Heritage”, Whittles Publishing, 2016.

[3] G. Bitelli, C. Balletti, R. Brumana, L. Barazzetti, M.G. D'Urso, F. Rinaudo, G. Tucci, “The GAMHer Research Project for Metric Documentation of Cultural Heritage: Current Developments”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W11, 239-246, 2019.

[4] M. Pigozzi, “Ricerca umanistica e Diagnostica per il Restauro. Bologna: il caso Curti in città e in villa”, Ed. TIP. LE. CO., 2010.

[5] G. Bitelli, M. Dellapasqua, V.A. Girelli, E. Sanchini, M.A. Tini, “3D Geomatics Techniques for an Integrated Approach to Cultural Heritage Knowledge: the Case of San Michele in Acerboli’s Church in Santarcangelo di Romagna”. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-5/W1, 291-296, 2017.

[6] V.A. Girelli, M.A. Tini, M. Dellapasqua, G. Bitelli, “High resolution 3D acquisition and modelling in Cultural Heritage knowledge and restoration projects: the survey of the Fountain of Neptune in Bologna”, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W11, pp. 573-578, 2019.

[7] R. Napolitano, M. Hess, B. Glisic, “Integrating Non-Destructive Testing, Laser Scanning, and Numerical Modeling for Damage Assessment: The Room of the Elements”, Heritage, 2, pp. 151-168, 2019.

[8] C. Suchocki, J. Katzer, and A. Panuś, “Remote Sensing to Estimate Saturation Differences of Chosen Building Materials Using Terrestrial Laser Scanner,” Reports on Geodesy and Geoinformatics. vol. 103, no. 1, pp. 94–105, 2017.

[9] M. Oren and S.K. Nayar, “Generalization of Lambert’s reflectance model.” In: Proceedings of the 21st annual conference on Computer graphics and interactive techniques - SIGGRAPH ’94, pp. 239–246, 1994.

[10] T. Voegtle, I. Schwab, and T. Landes, “Influences of different materials on the measurements of a terrestrial laser scanner (TLS),” In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, pp. 1061–1066, 2008.

[11] C. Suchocki and J. Katzer, “Terrestrial laser scanning harnessed for moisture detection in building materials – Problems and limitations,” Automation in Construction, vol. 94, pp. 127–134, 2018.

[12] S. Kaasalainen, A. Jaakkola, M. Kaasalainen, A. Krooks, and A. Kukko, “Analysis of incidence angle and distance effects on terrestrial laser scanner intensity: Search for correction methods”, Remote Sensing, vol. 3, no. 10, pp. 2207–2221, 2011.