

3D Point Cloud Model Color Adjustment by Combining Terrestrial Laser Scanner and Close Range Photogrammetry Datasets

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Abstract—3D models obtained with advanced survey techniques such as close-range photogrammetry and laser scanner are nowadays particularly appreciated in Cultural Heritage and Archaeology fields. In order to produce high quality models representing archaeological evidences and anthropological artifacts, the appearance of the model (i.e. color) beyond the geometric accuracy, is not a negligible aspect. The integration of the close-range photogrammetry survey techniques with the laser scanner is still a topic of study and research. By combining point cloud data sets of the same object generated with both technologies, or with the same technology but registered in different moment and/or natural light condition, could construct a final point cloud with accentuated color dissimilarities. In this paper, a methodology to uniform the different data sets, to improve the chromatic quality and to highlight further details by balancing the point color will be presented.

Keywords—Color models, cultural heritage, laser scanner, photogrammetry, point cloud color.

I. INTRODUCTION

THE application of modern survey techniques, such as Close-Range Photogrammetry or Laser Scanner (terrestrial and aerial) [1], [2], in the field of Cultural Heritage are nowadays widely employed due to their capability to produce three-dimensional point clouds in a fast as well as accurate mode [3]. While in the past, these two techniques have been often treated as two separate methodologies, comparing them in terms of accuracy, cost and flexibility [4], [5], recently they started to be considered as complementary [6], [7]. The benefit of integrating these two technologies is to take the advantage of the terrestrial laser scanner (TLS) capability to directly acquire dense colored cloud with the flexibility of the photogrammetry to operate even in exceptional condition. The first one need to acquire data for a fixed time with the instrument set on the ground or on a safe and static structure even in poor light condition: nevertheless, the acquisition of horizontal flat structures (e.g. summit of structure walls) may be difficult (i.e. unsafe) or unsuitable as it could require a huge amount of scans to regularly cover the entire structure to be surveyed. The latter, may be used even on mobile platforms (such as cranes, UAVs, aerostatic balloons, etc.) but requires a balanced exposure to obtain sharp

images.

The used test area is the archaeological excavation site in activity for the construction of the new Line 1 and Line 6 underground station “Municipio” in Naples (Italy). Because the construction site insists on a critical area of the historical center of Naples for a massive presence of ancient artifacts and structures below the actual planking level, a deep archaeological investigation has been preventively required in order to proceed with the infrastructure construction: the extraordinary concentration of archaeological evidences and artifacts found since the beginning of the construction activity of the station, required in recent years, the introduction of modern 3D survey techniques in order to carry out a much more detailed documentation and to contextually reduce the excavation time.

One of the not negligible aspects of an archaeological site, in such a situation, is the need to meet the construction management requests, especially in terms of time saving: in this sense, laser scanner and photogrammetry well fit this kind of needs, allowing to perform quick surveys and to reconstruct extremely realistic 3D models. Another aspect is the impossibility to survey, in some case, ancient structures all at once due to their dimensions and even due to organizational necessities for the progress of the construction activities: in such cases, these structures are usually subdivided in several sectors excavated and revealed separately. The surveys of each single sector are consequently performed in different moments (even in different years). This approach can bring to a final model where the different surveyed parts are still recognizable due to their nonhomogeneous texture. However, beyond the geometric accuracy of the final product, the appearance of the model (i.e. color) is not a negligible aspect from an archaeological point of view.

In the present paper, a few examples of integration between dense cloud data sets obtained with these two techniques, or between data sets registered with the same method but in different moments, will be reported. In these cases, particular attention will be demanded on the chromatic lack that usually comes out when surveys of the same object are performed in a different moment with different light conditions, especially if executed outside. A methodology to make more homogeneous the different data sets concerning the same surveyed object is then presented and discussed.

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II. POINT CLOUD COLOR STRUCTURE: TRANSITION FROM *RGB* TO *HSL* AND *VICE VERSA*

The integration of data obtained with different acquisition sources requires, of course, the homogeneity of the data format that must be processed and combined together. The *RGB* color model is an international color representation to digitally codify the color information: the specifications of this model have been defined by the Commission Internationale de l'Éclairage (CIE) in 1931. Laser scanner cloud files usually are registered by following the *XYZIRGB* format (*XYZ* for the spatial coordinates, *I* for the intensity and *RGB* for the point color). ASCII file is an "open" and relatively common format which is compatible with almost all commercial software. At any rate, such file structure is actually considered far from being "optimized". A much more suitable file format for laser data is the *LAS* one (Lidar Exchange Format), a binary and public file format with precise specifications about its digital structure approved by the American Society for Photogrammetry and Remote Sensing (ASPRS): this file format is widely employed by several software developers [8]-[11].

Beyond the *RGB* one, two more common color models are usually employed: the *HSV* (Hue-Saturation-Value) and *HSL* (Hue-Saturation-Lightness) [12] created by Alfred H. Munsell in the early 1900s. They are represented by using the cylindrical coordinate system, where the Hue is the angle around the cylinder axis, the Saturation is the distance from the axis while the Value/Lightness is the distance along the axis.

Hue represents the color perception (red, yellow, green, blue, and purple) and varies from 0° to 360°, where 0° corresponds to the Red, 120° to the Green and 240° to the Blue.

The Saturation represents the "purity" of the color and varies from 0% to 100%: by decreasing the Saturation, color appears more pale. The highest value represents the full saturation (100%), while the minimum (0%) is equivalent to the grayscale.

The Value and Lightness are the quality by which we distinguish a light color from a dark one [13] and its value varies from 0% to 100%.



Fig. 1 Representation example of lightness values [14]

HSV and *HSL* models are particularly useful because they describe the colors in a way closer to the human perception [15]. By considering the cylindrical coordinate system and by choosing a Lightness value, Hue and Saturation are equivalent to the polar coordinates of any point in the plane [14]. An exemplificative representation of the *HSL* model by varying the lightness is shown in Fig. 1.

The chosen model in the present work for color management is the *HSL*. The following equations show the mathematical relationships that allow the passage from the *RGB* system to the *HSL* one [16]:

$$\begin{cases} H = \frac{1}{2\pi} \arctg\left(\frac{2R-G-B}{\sqrt{3(G-B)}}\right) \\ S = \sqrt{R^2 + G^2 + B^2 - RG - RB - BG} \\ L = \frac{1}{3}(R+G+B) \end{cases} \quad (1)$$

The adopted algorithm that allows this transformation from *RGB* to *HSL* and *vice versa* was implemented by Smith [17] and subsequently by Fishkin [18].

III. TEXTURE HOMOGENEITY ISSUE COMPARING LASER SCANNER AND PHOTGRAMMETRIC MODELS

Since 2012, a more detailed and accurate documentation of archaeological evidences and artifacts found within the construction site of the "Municipio" underground station has been required. Laser Scanner and Photogrammetry survey techniques have been employed to satisfy such requests, allowing to perform surveys in a quick manner and to reconstruct extremely realistic 3D models. While at the beginning, these methodologies have been considered separately by processing data to obtain two separate products (3D point clouds with TLS and orthophotos with Photogrammetry), the recent developments in automatic dense point cloud extraction, with the photogrammetric approach, have made the latter competitive also for 3D point cloud model reconstruction.

Laser scanner is usually competitive for indoors surveys (e.g. mining, tunneling, etc.) allowing to perform textured scans even in poor light conditions but keeping mostly a uniform color brightness with the right illumination (natural and/or artificial) once the scans are edited and joined to obtain the final 3D model. On the other hand, the quality of outdoors scans in terms of texture are often influenced by the exterior light situation: unless we have a diffused or natural cloudy light condition during the entire acquisition session, the constant presence of sun and shadows could have a negative impact on the final result. In addition, by working in an underground construction area, with almost imposed deadlines, it is rarely possible to postpone a survey until a better situation comes, especially when several scans must be done for a single session.

Digital photogrammetry is a much flexible technique that allows to reach better results in terms of appearance (texture) of the 3D models in less time (depending on the object complexity), thanks to a usually higher resolution of the images employed to compute the model texture, compared to the panoramic ones normally used to texturize the laser scanner clouds. In addition, the points composing the clouds

obtained with image matching based algorithms are usually colored by reading and averaging the *RGB* values of the pixels that generated the specific point of the cloud, compared to the laser scanner technique where each scan is colored separately, with no color averaging for the neighboring scans. However, the image-based approach can run into some limitation when big and/or complex objects must be acquired to obtain accurate and high resolution models in case of indoors surveys. In such cases, a much more attention during the acquisition step must be kept, especially regarding the backlit and a reduced depth of field; in addition, extra equipment, such as tripods, spotlights, etc., could be also required, considerably extending the acquisition and the editing time as well.

One of the issues that can emerge during an archaeological investigation within a construction site, like the one of an underground station, is the need to proceed by dividing the whole area into subsectors and to excavate them separately. By following this approach, huge structures, such as ancient defensive walls, are revealed in different temporal moments (even in different years) and the surveys of each single part have to be also performed separately. In these cases, atmospheric agents, different light conditions and/or eventually the different employed survey equipment during the acquisition of each structure portion can bring to a final model, a condition where each part is not well uniformed to the neighboring one. If the structure can be naturally shadowed by neighboring buildings during a specific time of the day and the object to survey is not particularly complex, the photogrammetric approach can be preferred to quickly acquire images with a “just-in-time” approach, taking the advantage of a suitable natural light condition, sensibly reducing the irregularity of the texture once the parts are assembled.

In the following paragraphs, a few examples of acquisition, 3D model restitution and assembling with the above described problematics will be shown and discussed, by focalizing on the texture issue in the assembling phase. For these tests, laser data have been registered with a Leica HDS7000 phase-based laser scanner, textured by using a DSLR Canon 5D Mark II camera with a 15mm fisheye lens and processed with the provided software Leica HDS Cyclone; photogrammetric data have been collected with the same DSLR-Camera body equipped with a 24mm fixed lens and processed with Agisoft Photoscan software.

IV. PHOTGRAMMETRIC AND LASER SCANNER DATA ACQUISITION, PROCESSING AND COLOR ADJUSTMENT PIPELINE

Nowadays, the main pipelines for laser and photogrammetric data acquisition and processing follow a more or less standardized workflow. The acquired laser scans have to be aligned to each other in order to build a single point cloud block of the surveyed object, they must be singularly textured to obtain a much more realistic 3D model and then the block needs to be georeferenced in order to provide to the final user real metrical information and coordinates of the surveyed object. For the photogrammetric pipeline case, the

acquired images have to be aligned to each other, the model block must be georeferenced (or at least scaled) and then the images must be elaborated to automatically extract the final dense point cloud. All these steps are briefly summarized in the workflow diagram reported in Fig. 2.

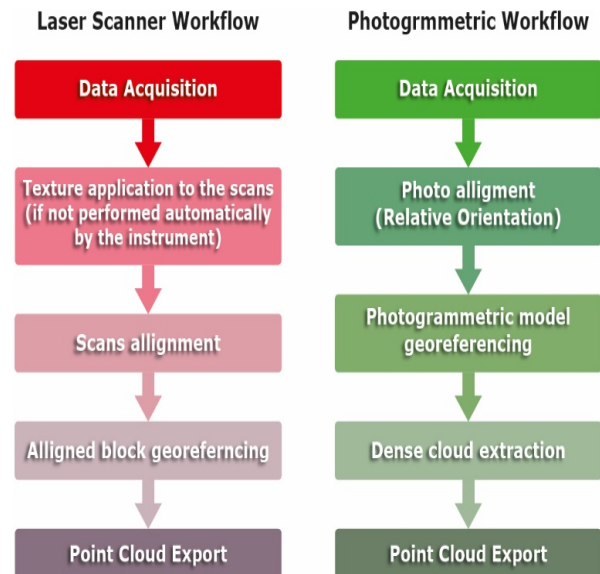


Fig. 2 Laser Scanner (left) and Photogrammetric (right) data processing workflow

Once the point clouds have been obtained, they are imported into a common visualization software in order to assemble them, obtaining a unique 3D model of the object and evaluating possible lacks in terms of texture differences and non-homogeneity. As discussed above, the surveys of different parts of the same object performed in different moments could easily cause a texture homogeneity issue in the final 3D model.

One of the possible ways to have a positive effect on the model's texture quality would be to correct the original raw data, which means operate on each panoramic image for the laser scans and on each single image frame in case of an acquisition with the photogrammetric technique. However, an attempt to operate in such a way would be unaffordable and almost impossible to execute, especially in the second case: indeed, such an approach would request an intervention on hundreds (or even more than a thousand) of images, with a possible negative influence on geometric quality as a consequence, beyond the need to operate singularly on each image, which is also extremely time consuming. Lastly, the availability of the original data could not be always insured.

The proposed developed algorithm aims to modify each single cloud texture by adapting it to the adjacent one without the need to be in possession of the survey raw data. For such correction, the chosen color model with which modify the texture is the *HSL* one; the algorithm allows adjustment of the texture by operating on Hue, Lightness and Saturation in terms of percentage of the original *HSL* values of the cloud to modify.

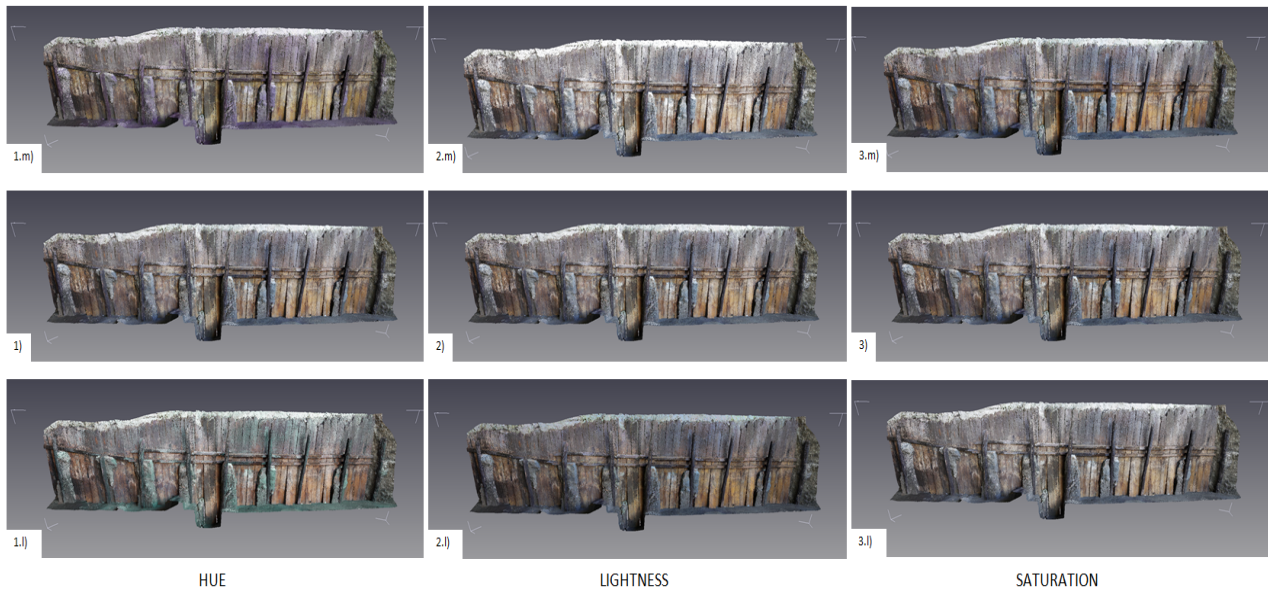


Fig. 3 Hue, Lightness and Saturation variation effect applied on a test point cloud

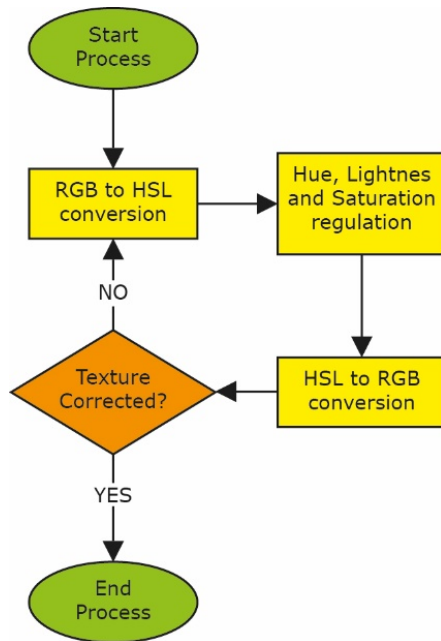


Fig. 4 Point cloud color adjustment flowchart

In order to graphically understand the impact on the color of the point cloud by varying the value of each component of the *HSL* model, an example has been reported in Fig. 3: Hue, Lightness and Saturation (respectively 1st, 2nd and 3rd column in Fig. 3) have been reduced and increased by varying them of 20% in respect to the original cloud values (second row in Fig. 3). By increasing and decreasing these components (the results are reported respectively in the 1st and 3rd column), it is possible assert that:

- The increase of the Hue value leads to a general purple color of the cloud, while its reduction to a green one;
- The increase/decrease of the Lightness contributes to obtain a clearer/darker points cloud;

- By increasing the Saturation level, a higher intensity of the cloud color can be carried out, while by decreasing it, an opaquer cloud is obtained.

The comparison and the color adjustment procedure are iteratively repeated until sufficient homogeneous texture for the entire model is obtained. The graphical flowchart of the methodology applied in this work is well explained in Fig. 4.

V. CASE STUDY: APPLICATION OF THE METHODOLOGY TO ASSEMBLED DATA SETS

In order to show the efficacy of this method, a series of three application case will follow.

The first application case is the survey of a portion of the surrounding defensive wall of Castel Nuovo in Naples, which has a length of about 60 meters and a maximum height of about 8 meters, with the façade north-facing. Due to the dimension of such portion and to organizational necessities for the progress of the construction activities, the excavation, and consequently, its survey has been performed in three different moments. All the data sets have been collected by using the TLS technique: the essential parameters of the survey are briefly summarized in Table I. In this case, the illumination condition has definitively influenced the texture quality due to the fact that the three data sets have been collected with different light conditions (Table I), leading to an accentuate chromatic difference on the assembled 3D model, which is clearly visible in Fig. 5 (upper image). By applying the proposed algorithm, the contrast between one cloud and the neighboring ones has been sensibly reduced and the transition between the clouds appears smoother than the original one, increasing the homogeneity of the whole 3D model.

Table II reports the parameters applied to the data sets that allow obtaining the final results (lower image in Fig. 5).

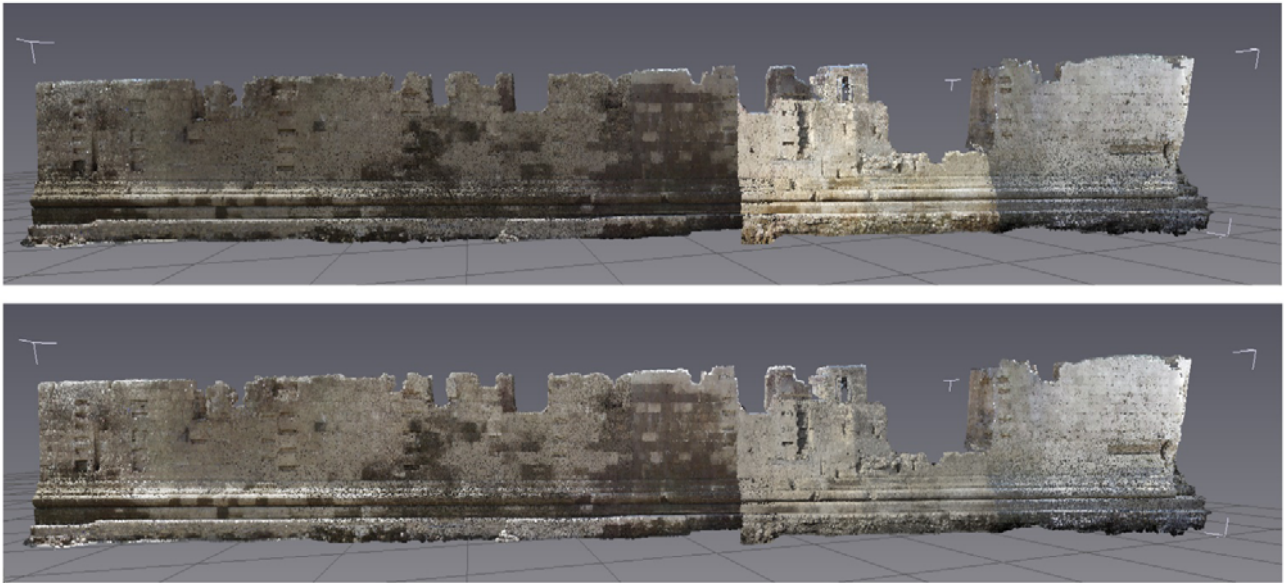


Fig. 5 Portion of the defensive surrounding wall of Castel Nuovo in Naples: comparison between the original TLS survey (upper image) and the processed one with the proposed method (lower image)

The second application concerns the combining of two data sets obtained with both the considered survey techniques: TLS, and close range photogrammetry. In this case, it was requested to survey and reconstruct a 3D model of a portion of the sea bottom, on which a certain number of tracks related to anthropic activities have been found.

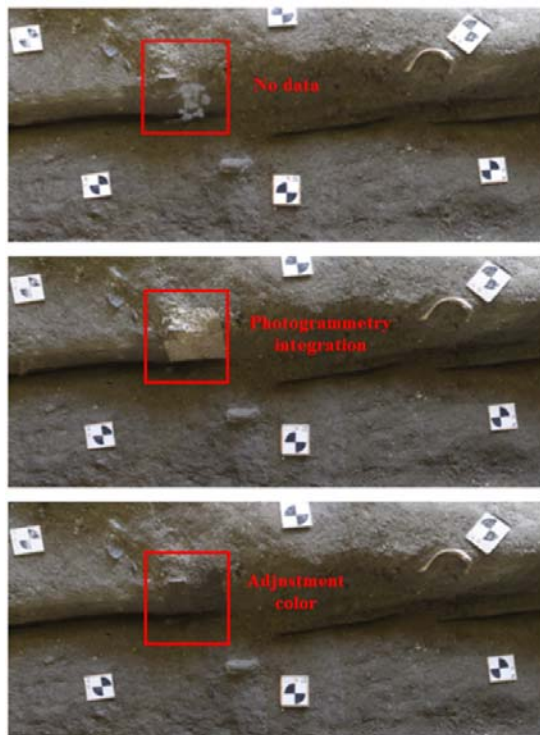


Fig. 6 Integration of Laser scanner and photogrammetric point clouds before and after the color adjustment

TABLE I
 SUMMARY OF SURVEY INFORMATION

Surveyed part	Left	Center	Right
Survey date	26 May 2014	28 July 2015	18 July 2014
Local Time	11:00-13:30	8:20-8:55	16:40-17:30
Weather	Sunny		
Illumination condition on the wall	Partially shadowed	Totally exposed to the sunlight	Totally shadowed
No. scans	6	5	3
No. points	61.963.182	6.680.845	26.835.410

TABLE II
 HUE, SATURATION AND LIGHTNESS INCREASE/DECREASE VALUES APPLIED TO THE THREE DATA SETS

Surveyed part	Left	Center	Right
Hue	+2%	+3%	0%
Saturation	0%	-40%	+7%
Lightness	+30%	-20%	+10%

Due to the poor light conditions (the archaeological excavation proceeded below a reinforced concrete slab), the laser scanner has been preferred in order to collect data in less time with a better accuracy. However, the physical limitations of the area made it impossible to obtain a perfect cloud without data gaps (upper image Fig. 6). To overcome this situation, a photogrammetric survey limited to these uncompleted portions has also been performed by employing a photographic tripod, in order to make long shutter time and a so keeping a good depth field. However, by checking the central image in Fig. 5, it is possible to realize how the photogrammetric point clouds appears much clearer than the one obtained with TLS: such a condition is the result of an overexposure of 1 f-stop during the image acquisition phase, a choice made to keep a good image contrast to avoid failures or geometric accuracy lacks during the image-matching process. Therefore, by using the developed script, it was possible to correct the color of the point clouds and to extremely

homogenize the two different data sets, completely recovering the original TLS cloud gaps.

The third and last case concerns the survey of a containment wall made with the tuff blocks technique and reinforced with weirs on one side ("A" in Fig. 7), together with a second ancient wall built put side by side and made with paneled masonry technique ("B" in Fig. 7).

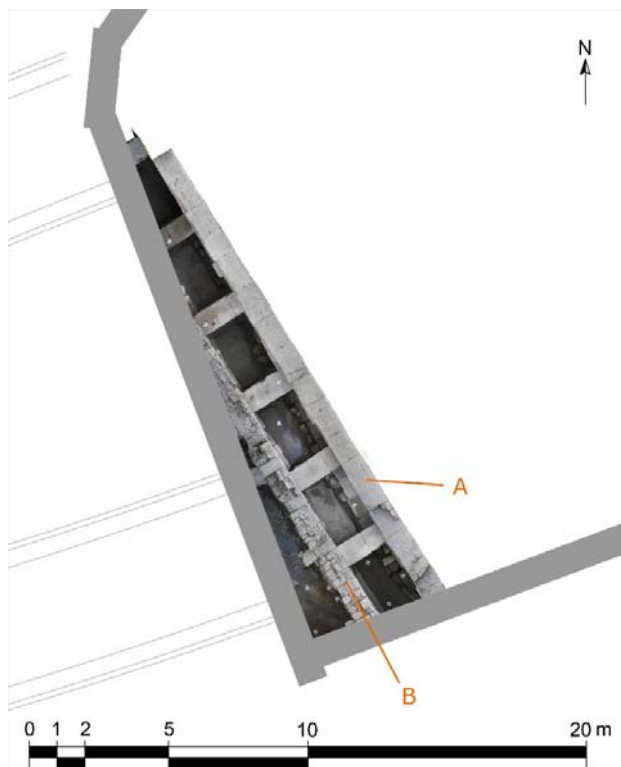


Fig. 7 Position of the surveyed structure within the excavation site

Due to their dimensions and to the position of the surrounding reinforced concrete bulkheads, there were just a few possible laser scanner acquiring positions to take advantage of; in addition, they did not allow to acquire with enough accuracy the summit of both the walls, and the risk level (in terms of safety for the operator and for the instrument as well) was too high to consider the positioning of the instrument on the walls' summits itself. In order to recover such a gap and to obtain a 3D cloud with a uniform resolution (for both vertical and horizontal sides of the walls), the photogrammetric technique was employed to perform the acquisition of the top of the walls, by making use of a special wearable crane on which the camera is coupled, allowing to keep the camera itself three meters above the ground and to perform both nadiral and tilted images to better compute the cloud around the corners of the walls. In the end, a total amount of 22 textured laser scans with a resolution of 6.3 mm at 10 m have been performed for the vertical parts of the walls, while 573 photos have been taken to reconstruct the top segments.

Fig. 8 (a) and (b) of report the results of the two separated survey sessions with the TLS and the close range

photogrammetry, respectively: in the first case, it is possible to verify how the space limitation for the scans lead to insufficient coverage of the upper parts of the walls, while the second case shows a better reconstruction of these parts by using the photogrammetric technique. After an adequate color adjustment and a precise editing around the common part of the two clouds, a perfect 3D model, consisting of about 150 million points has been finally obtained (Fig. 8 (c)).

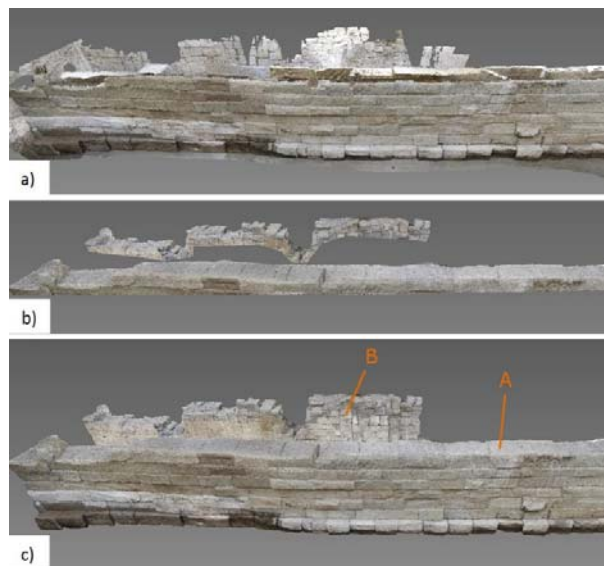


Fig. 8 (a) Laser point cloud; (b) Photogrammetry point cloud; (c) Integration of laser and photogrammetric point clouds after the application of the color adjustment process.

VI. CONCLUSION

The developed script above described permitted to sensibly improve the texture quality of 3D models, where disadvantageous light conditions during the acquisition session, which leads to poor homogeneity when such models are obtained by assembling different parts of models registered in a different moment. Indeed, as reported in the discussed case study, the chromatic correction of the individual data sets has allowed obtaining a unique and a much more uniform point cloud. Therefore, in cases where there is the necessity to merge multiple data sets or emphasize some particular area of a survey, this algorithm takes on great importance for the color quality improvement of the point clouds. Even if shown cases are purely referred to archaeological situations, this algorithm could be adapted and used also in other fields, such as civil engineering, architecture, etc., and more generally in all applications that require the integration of colored multiple point clouds.

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