3D RECONSTRUCTION OF THE *ROMAN DOMUS* IN THE ARCHAEOLOGICAL SITE OF *LYLIBAEUM* (MARSALA, ITALY)

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ABSTRACT:

Generally, terrestrial laser scanning surveys involve a rather large number of scans to ensure a high percentage of overlap required for the scan registration phase (target-based or point-based registration, cloud-to-cloud registration). These approaches result in data redundancy that could slow down both the acquisition and post-processing phases. In recent years, the technological evolution in the field of laser scanners has been directed to the development of devices that are able to perform an onsite pre-registration, to optimize the survey procedures and the reliability of the registration of the scan. The paper presents the results achieved during a terrestrial laser scanning survey carried out for the documentation and 3D reconstruction of the large and complex archaeological remains of the so-called Roman *Domus* in the archaeological site of *Lylibaeum* (Marsala, Italy). The survey was also conducted using a terrestrial laser scanner capable of pre-registering scans using a topographic approach. The pre-registration procedure and the data acquisition strategy have allowed to optimize the workflow and to obtain a 3D model of the Roman *Domus* with a high level of detail and area coverage.

1. INTRODUCTION

Terrestrial laser scanning (TLS) is one of the most widely used technologies for acquiring 3D data on large and complex (archaeological) scenes; it offers many advantages with respect to other surveying techniques (acquisition speed, reliability of data, etc..) and it allows to obtain point clouds even with high accuracy (even up to a few millimetres).

Starting from the TLS first applications in Cultural Heritage field, technology has changed a lot, improving performance of the systems; technological advances in data quality, software processing, workflow and ease of use have provided a significant improvement in productivity and efficiency, through fast, accurate, intuitive, portable and highly automated systems. Therefore, scan planning is still an important aspect of the survey in order to optimize the number of scans and times and, at the same time, to meet the required level of detail and data coverage (Díaz-Vilariño et al., 2019). This last issue involves the storage of several single 3D datasets in local coordinate reference systems and, consequently, the need to reference all scans to a unique coordinate reference system to create a global point cloud. This homogeneity in coordinates is achieved during the processing step of the registration of the scan.

In recent years, some laser scanners have been improved in order to provide users with an automatic pre-registration procedure in the field, without manual intervention, to quickly conduct quality control check and to make a better-informed decision on site.

Indeed, the process of point clouds registration is a key element of the laser scanner survey and can be a time-consuming process in the case of many scans. This step is critical for the quality of the final product and for errors that accumulate differently depending on the registration strategy applied (Rabbani et al., 2007). A considerable amount of works have been carried out on this subject in recent decades (Pomerleau et al., 2015, Cheng et al., 2018).

The registration task consists of a 3D transformation that is applied to the 3D coordinates of one or more point clouds to transform them into the same reference coordinate system. Depending on configuration and complexity of the scene, the registration may involve two point clouds (pairwise registration) or more point clouds (global registration) (Lachat et al., 2018).

Conventional cloud-to-cloud registration strategy frequently applies a coarse-to-fine registration method. The first coarse registration is used to determine a good initial position between point clouds and results in pre-alignment of the scans. The registration can be done manually by placing targets (Becerik-Gerber et al., 2011), using natural features or 2D information from range or intensity images to derive characteristic points in 3D space (Weinmann et al., 2011).

Starting from the initial registration parameters, fine registration improves the accuracy of the pre-alignment (Wang et al., 2014). The aim of the fine cloud-to-cloud registration is to achieve a perfect overlap of point clouds using standard solutions based on Iterative Closest Point (ICP) algorithms and its variants to refine values and minimize error. The ICP algorithm is based on the iterative search of pairs of nearest points in two partially overlapping point clouds and estimates the transformation parameters between them to converge to a local minimum (Rajendra et al., 2014).

Although fine registration can get a more optimal solution than the one achieved through coarse registration, it converges to an optimal solution only if the coarse registration is already sufficiently close to the optimal solution and point clouds share a large overlapping region (Wang et al., 2014). Moreover, all of these methods need large overlapping regions between two datasets and require pre-processing to extract features, which is time-consuming. Clearly, for a large number of scans, an automatically approach could be very useful. The possibility to realize it in the field becomes a crucial goal.

In the archaeological field, all these improvements play a crucial role in the choice of TLS survey to record and analyse archaeological remains. In particular, the complexity and peculiarity of the archaeological contexts often could make the survey and the acquisition of complete and accurate 3D data

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difficult (Gonzalez-Aguilera et al., 2017). At the same time, device optical limitation and spatial constraints require multiple scans to completely acquire the scene of interest.

In this context, the paper presents the results of a TLS survey to record and manage the complex archaeological site of the so-called Roman *Domus* in the archaeological site of *Lylibaeum* (Marsala, Italy). The remains of *Lilybaeum*, the ancient city of Marsala, are preserved inside the Archaeological Park of Lilibeo. *Lylibaeum* was founded in the IV century B.C. by the Punic and had a long life until the Roman Empire. The Archaeological Park of Lilibeo preserves significant remains of the ancient city as the *Insulae* I, II and III, located in the north-east area of the Park (Giglio, Vecchio, 2006). In particular, the Roman *Domus*, excavated first in 1939, completely occupies the area of the *Insula* I. In order to protect these remains, the area was partly covered by a modern concrete roof (Figure 1). The *Domus* still shows many rooms and thermal baths and it is decorated with polychrome mosaics (Figure 2).

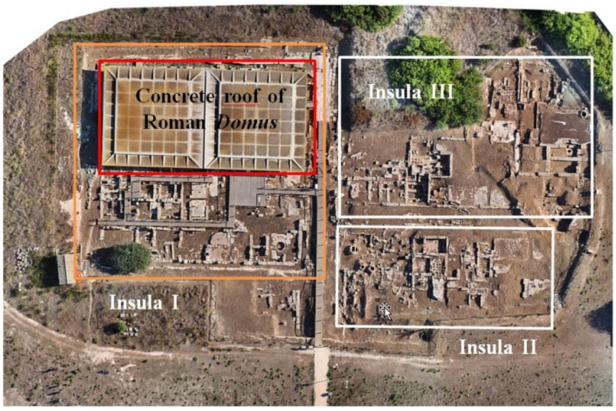


Figure1. Area of *Insulae* I, II, III and the Roman *Domus*.

Figure 2. Rooms and thermal baths of the Roman *Domus*.

The Roman *Domus* TLS survey is part of an ongoing documentation campaign, started in 2017 and aimed to carry out a complete 3D documentation of the main remains of the site for the achievement of the archaeological map of *Lylibaeum* (Ebolese et al., 2019a; Fazio et al., 2019). A previous UAV-based photogrammetric survey was allowed to obtain complete documentation of the large area (ca. 6000 m^2) of the *Insulae* I, II and III without however documenting the part under the concrete roof (Ebolese et al., 2019a).

The TLS survey was planned to document the remaining covered area of the Roman *Domus*. The area acquired in 3D is ca. 46 m long and 21 m wide (ca. 1000 m^2). The survey was first carried out with a Topcon GLS-2000, a full-dome time-of-flight laser scanner (TOPCON, 2018). Additional scans were also performed with a Faro Focus 3D laser scanner in order to complete the 3D model of the Roman *Domus*.

2. SURVEY PLANNING AND DATA ACQUISITION

The TLS survey was carefully planned, taking into account several factors that characterize the morphology of the archaeological area. The complexity of the structure and its geometric irregularities made difficult to use the standard approach (point clouds with high percentages of overlap measured from many scan positions). In fact, the wooden walkways that characterize the *Domus* area and that constitute barriers among the various zones (Figure 3), the presence of large roof pillars, the different heights and shapes of the preserved structures, which cause many shaded areas, could force to carry out a very high number of scans.

Figure 3. Wooden walkways on the Roman *Domus*.

To overcome the complexity of the structure that could make cloud-to-cloud registration very difficult, it was planned to perform first an overall survey of the entire area by connecting scan positions using a topographic approach, then integrating the most problematic areas with "single scans". The first survey needed to acquire a general point cloud of the Roman *Domus* that can be used as a reference for cloud-to-cloud registration of the "single scans". The TLS survey was suitable to take advantage of the topographic approach, by the traverse method, provided by the Topcon GLS-2000 for scans registration (Ebolese et al., 2019b). In fact, the Topcon GLS-2000 allows planning scan points along a traverse. The traverse method allows to set the point ("Occupation point" or "OCC point") from which to perform the scan and from which to measure the previous scan point ("Backsight point" or "BS point"). Scans are automatically registered in a topographic way, even without large overlapping areas. This is an important requirement for a site with many barriers and articulated structures as the *Domus* area.

The complexity of the site has required different acquisition campaigns; a first campaign was performed with a Topcon GLS-2000, the second with a Faro Focus 3D. In the first survey twenty scan points were planned (Figure 4); nine were arranged along a traverse path, using the topographic approach of the GLS-2000 (from DOMU1 scan to DOMU9 scan), eleven were carried out without any connection to the traverse path but as "single scans" (from DOMU10 scan to DOMU20 scan).

Figure 4. Roman *Domus* plan with Tocon GLS-2000 scan positions: in red the traverse scans and in violet the "single scans" (roof pillars in blue and wooden walkways in green and grey).

The scans arranged along the traverse path allowed generating a first reference point cloud of the whole site. During the onsite survey, first two fixed tripods were placed on the first and the last scan points. Instead, the other two tripods were moved, following the planned path of the traverse, to the next scan points and to the back- and foresight scan positions. No targets were positioned and measured.

In order to georeference the final TLS model in the same reference system of the previous UAV survey, the first scan position (DOMU1) was placed on a point of the topographic network, previously measured by a topographic survey (Ebolese et al., 2019a). From this scan point, a point of the topographic network, external to the traverse, was measured with the laser scanner (DOMU0) (Figure 5). The coordinates of the first scan position (DOMU1) and of the point external to the traverse (DOMU0) have been set equal to the coordinates of the points of the topographic reference system. In this way, it was possible to georeference all the traverse scans in the topographic reference system used for all the previous surveys within the Archaeological Park of “Lilibeo”.

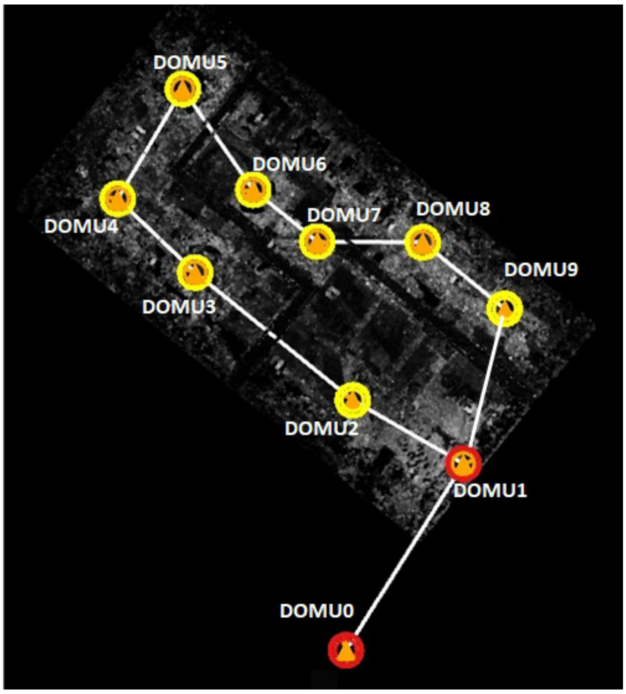


Figure 5. Traverse path of the scan points

The “single scans” were carried out to cover the most critical areas and to try to close the biggest gaps in the reference point cloud of the Roman *Domus*. The figure 6 shows the approximate location of these scans (Figure 6).

All the scans acquired with the Topcon GLS-2000 were carried out with a full dome field of views (360° in horizontal direction and 270° in vertical direction) and an average sampling step of 12.5 mm at 10 m.

In order to fill all model gaps and also to achieve detailed scans of some rooms, a second acquisition campaign of “single scans” was needed. Therefore, thirty-three additional scans were planned using a Faro Focus 3D laser scanner (Figure 7). The Faro scans were arranged mainly in the north and north-west area of the *Domus* were many small rooms are located. Detailed scans were performed with higher resolutions (of 3 or 6 mm at 10 m), by setting different horizontal and vertical field of views (Table 1). They were used to complete the 3D model of the *Domus*.

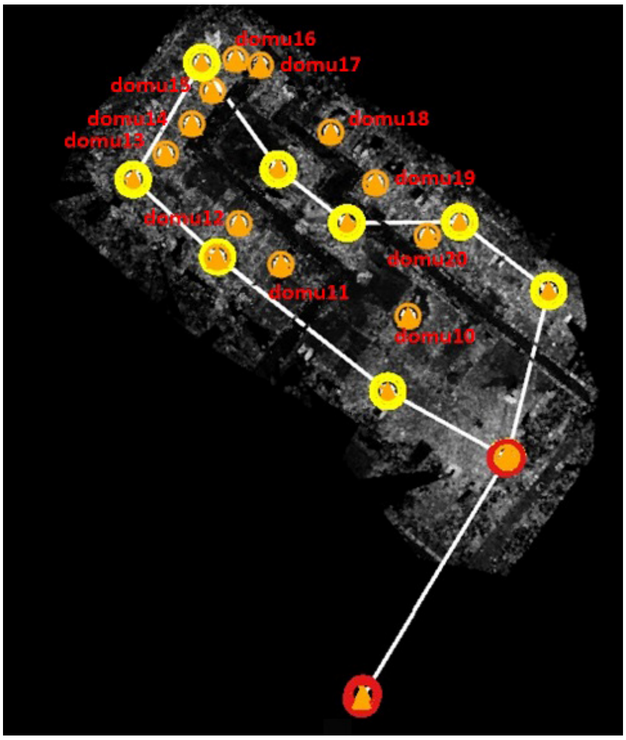


Figure 6. Traverse path of the first nine scan points (yellow circle) and the eleven “single scans” (orange circle).

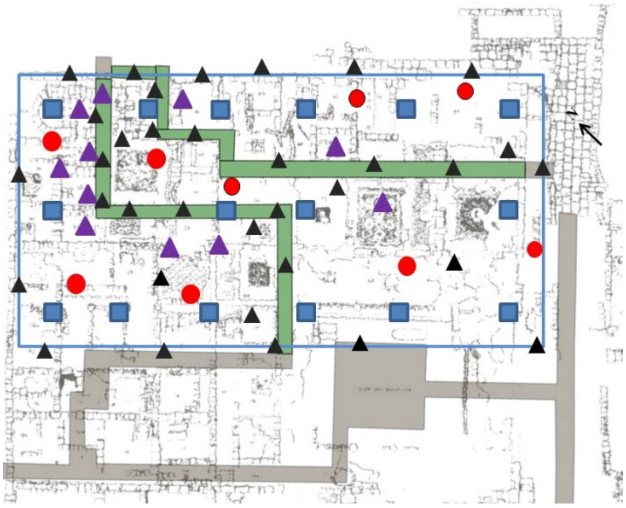


Figure 7. Roman *Domus* plan with scan positions of the two campaigns: Tocon GLS-2000 scans (in red and violet) and Faro Focus scans (in black).

N. of scans	Horizontal field of view	Resolution
9	360°	3 mm @ 10m
5	180°	3 mm @ 10m
9	360°	6 mm @ 10m
10	180°	6 mm @ 10m

Table 1. Faro scans with different settings of the horizontal field of view and resolution

3. DATA PROCESSING

In order to integrate point cloud datasets obtained with diverse cameras and acquired in two different moments, with different light and weather conditions, particular attention was given to the chromatic differences as first. Therefore, panoramic images generated by Topcon GLS-2000 were imported and adjusted in Photoshop Camera Raw by Adobe to try to make more homogeneous the different datasets (Figure 8).

All Topcon GLS-2000 scans were processed with Magnet Collage package by Topcon Positioning.

All scans acquired along the traverse were automatically registered (Figure 9).

Figure 8. Panoramic image first (left) and after (right) Camera Raw adjustment

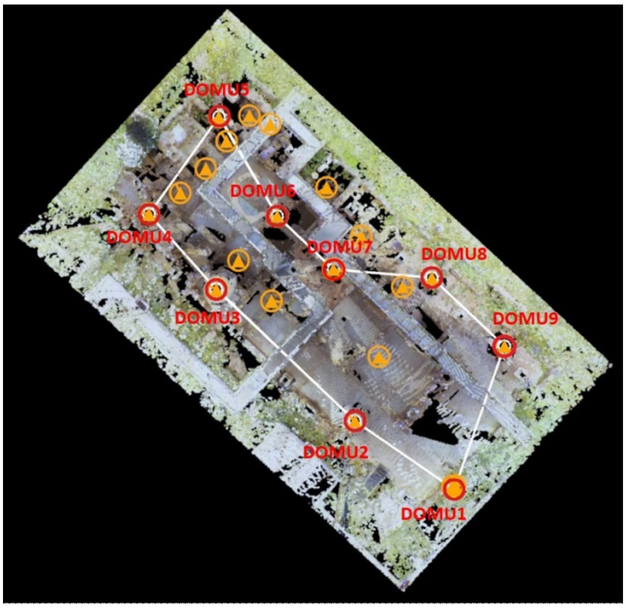


Figure 9. Magnet Collage automatic registration of scan points along the traverse

Thanks to this topographic approach, it was not necessary to have the traditional large area of overlapping among all scans. It became important during the acquisition phase to overcome the problem of the wooden walkways.

The check on the traverse scan registration was made on scan points coordinates Root Mean Square (RMS) errors and maximum deviation (MAX) calculated by Magnet Collage for each scan point with respect to the “Backsight point”. These values are about a few millimetres; in some scan points only for the Z coordinate, the max residual reaches the centimetre (Table 2).

OCC/BS Registration	**X [m]**	**Y [m]**	**Z [m]**
RMS	0.002	0.003	0.008
MAX	0.003	0.005	0.011

Table 2. Magnet Collage residual and maximum deviation of automatic registration between DOMU1 and DOMU2.

A point cloud, along the traverse, of about 49 million points was achieved. After a first noise filtering and after removing the points of the roof, the final point cloud was of about 28 million points. This point cloud was used as a reference to register all the “single scans”.

The eleven “single scans” acquired with the Topcon GLS-2000 were first edited applying noise reduction filter and deleting the points most distant from the areas of interest; then, they were registered on the reference point cloud with a traditional cloud-to-cloud process. RMS errors of cloud-to-cloud registration between the reference point cloud and each “single scans” was in the order of 4÷5 millimetres.

After the registration process, a merged point cloud of about 46 million points was generated from all Topcon GLS-2000 scans (Figure 10).

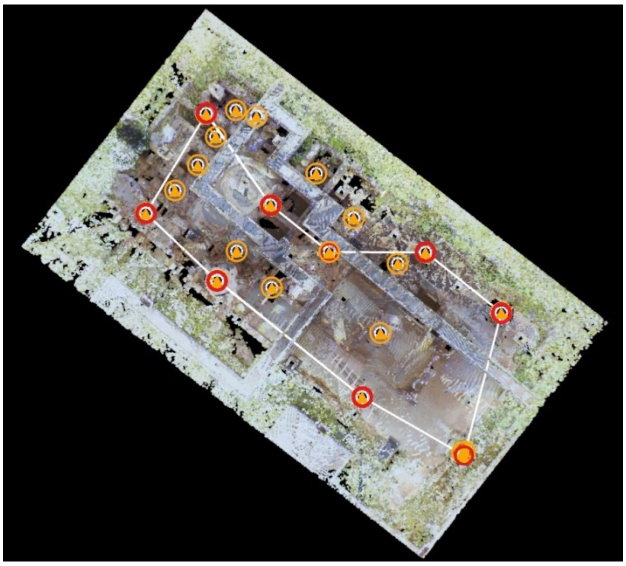
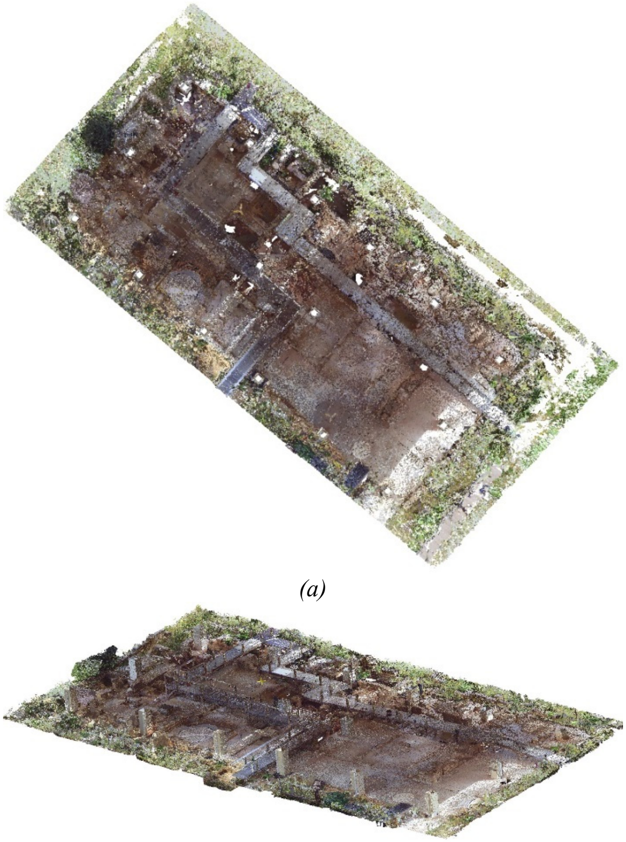


Figure 10. Cloud-to-Cloud registration between the 9 traverse and the 11 “single scans”.

Finally, in order to register the merged Topcon GLS-2000 point cloud with all remaining Faro Focus 3D scans, a new project was created in Autodesk Recap. Topcon GLS-2000 point cloud was exported from Magnet Collage and imported in Recap package. Instead, all the thirty-three Faro Focus 3D scans were directly imported in Recap. The “Auto register” tool of Autodesk Recap was used for scans registration; this tool has identified two groups, one with the reference Topcon GLS-2000 point cloud and the second with the Faro Focus 3D scans, that were automatically registered by a cloud-to-cloud process.

The registered scans were finally merged to generate a complete 3D model of the Roman *Domus* obtaining a point cloud of about 460 million points. This dataset had excessive data redundancy and was difficult to manage. A subsample of the final point cloud was thus carried out using CloudCompare software with an average resolution of 6 mm. A final point cloud of the Roman *Domus* of about 60 million points was generated (Figure 11).


(a)

(b)

Figure 11. Subsampled point cloud of the Roman *Domus*: (a) plan view, (b) 3D view.

The final model of the Roman *Domus*, generated from the TLS survey, was used to complete the previous UAV 3D model of the *Insulae* area (with the *Domus* covered by the roof) (Figure 12). Thanks to the topographic approach of the GLS-2000 survey, the final TLS model of the *Domus* was already georeferenced in the same coordinate system of the UAV model. Therefore, the two 3D models were automatically aligned in CloudCompare (Figure 13).


Figure 12. UAV 3D model of the whole *Insuale* archaeological area with the covered Roman *Domus*


Figure 13. Integration of UAV model of the whole *Insuale* archaeological area and TLS model of the Roman *Domus*

4. CONCLUSIONS

TLS technology is the fastest for large scale and complex (archaeological) scenes data acquisition. At the same time, the necessity to entirely record archaeological sites, with spatial and shape complexity, device optical limitation and spatial constraints, requires multiple scans to completely acquire the scene of interest slowing down both the acquisition and post-processing phase.

Technological evolution in laser scanners field has been directed towards the development of devices that can be able to perform onsite pre-registration of scans, to optimize the survey procedures and the reliability of the recording phase.

The paper presents the results of a TLS survey carried out to document the remains of the so-called Roman *Domus* in the Archaeological Park of Lilibeo. Fifty-three scans were planned to acquire the overall archaeological area. The employment of a device (a Topcon GLS-2000 laser scanner) able to pre-register scans in the field helped and accelerated the post-processing step. The laser scanner survey was planned to acquire a first point cloud of almost the entire area of interest using a topographic approach for scan registration; the scans were acquired along a traverse path. This process allowed to pre-register this scans group and to quickly obtain a reference point cloud, in order to plan a second TLS survey and to complete the 3D model of the Roman *Domus*. Different software needed to process all datasets and, in order to integrate all scans, particular attention was given to the chromatic uniformity of the point clouds.

A complete 3D model of the whole archaeological area of *Insulae* was achieved. If it was not possible to further reduce the number of scan points, the use of a topographic approach for scans registration was essential to process successfully all data. The possibility to use the coordinates of topographic points allowed to georeference the final 3D model in the same reference system of the previous UAV model of the whole archaeological area. Unfortunately, the problem with this data integration is the lack of colour homogeneity, which remains one of the main issues.

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