

HIGH-RESOLUTION DIGITAL SURVEY OF FLOORS: A NEW PROTOTYPE FOR EFFICIENT PHOTOGRAMMETRIC ACQUISITION

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ABSTRACT:

High-resolution surveying of historical floors is a very common practice in both research and everyday life. The type of floors typically concerned are made of mosaic, marble and stone. Because of their intrinsic characteristics, their survey typically requires very high-resolution results, to ensure excellent support for restoration, as well as in-depth knowledge of the artifact. In these cases, the focus must be kept on both geometric and radiometric content, to enable accurate metric representation and a rendering of colour and surfaces as close as possible to reality. In this research we propose a prototype of a photogrammetric acquisition system (under development) which tries to optimise the floor survey in terms of both geometric and colour documentation. In particular, the prototype makes use of the cross-polarisation technique with the aim of eliminating reflections from the images. The principle behind the prototype is the creation of a movable laboratory, a segregated space that allows excellent photographic acquisition even in difficult environmental conditions, which cannot always be controlled optimally. First tests showed its suitability and usefulness to reach the goal of a high resolution survey of historic floors.

1. INTRODUCTION

Floors belonging to historical buildings have always been a very important field of application in Geomatics for various reasons, such as their usual decorative richness and the need to achieve a highly detailed and precise representation. Because of these reasons, their digital surveys are typically conducted with photogrammetric techniques.

In general, the placement of pavements within buildings makes them easy to reach physically, but at the same time it constitutes a constraint for the photogrammetric survey. In fact, their close position to the manually held camera does not always allow for an optimal acquisition and can result in oblique images that make the post-processing phase more complex and less precise (because of the changing Ground Sample Distance GSD in the images). In this case, some alternative solutions could be implemented, for example by exploiting Unmanned Aerial Systems (which could be operated only outdoors), or using a camera mounted on a pole.

On another note, floors of historical buildings are also an important field of experimentation for the disciplines of conservation and restoration, that so very often partner with Geomatics. They constitute surfaces that are constantly exposed to deterioration and risk of damage because (unless musealised and therefore inaccessible) they need to support all the traffic of people (as well as vehicles, in some cases) passing through the area for touristic, functional and celebratory reasons.

Finally, there is one last important aspect to consider, in terms of survey: the floor material. In many cases, to embellish the environments, floors were conceived as highly decorated carpets, although made with various techniques (e.g. mosaic) and with different materials (e.g., glass tesserae, marble tesserae, marble or stone blocks). Each material, in addition to a different aesthetic

appearance, is characterised by a specific behaviour linked to the digitization technique implemented, whether it is laser scanning (noise due to penetration of the laser signal, as in Godin et al., 2001) or photogrammetry (reflections).

A first experience in this field was conducted for the survey of the floor of Basilica of San Marco, in Venice. By means of a traditional approach that integrated photogrammetry and topography, between 2000 and 2008, a research team from Politecnico di Milano acquired about 1,700 photogrammetric shots of the entire floor of the Basilica for a total of 2,600 m²: the goal was to obtain an overall geometric model of the pavement and an orthophoto representing each particle of the mosaic (Fregonese et al., 2006). At the time of that experiment, the camera was mounted on a cart at the height of about 2.3 m from the floor and the pictures were acquired in strips characterised by 60% longitudinal overlap and 20% transversal. Complete control of the light was not possible, but as the survey was performed during the night, the overall light settings, provided by artificial devices, was satisfactory, and not altered by sunlight. The entire floor of San Marco was thus acquired, and processed according to the photogrammetric method of bundle adjustment, to obtain the DSM and the high-resolution orthophoto.

Important developments in digital photogrammetry which happened since then (especially with multi-image and dense stereo matching forms) have also provided great support in the survey and documentation of historical pavements. The ability to capture images from different viewpoints (instead of according to a rigid gripping geometry) has facilitated the acquisition step and although the number of images used is now much higher than in the past, the automation of the system allows a much faster work pipeline.

However, it is necessary to develop an effective and well-defined procedure in order to guarantee high resolution surveys of floors

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and to avoid problems both from a geometric point of view and from a qualitative one. As far as geometric accuracy is concerned, the main problem arises when photographic acquisitions are inclined and not nadiral. Since the GSD follows the laws of perspective, the size of it varies according to the distance of the camera from the subject captured: small values for "near" pixels and much larger for "far" pixels. On the other hand, the qualitative problems, essentially, affect the ability to faithfully reproduce the surface of objects, regardless of the environmental conditions. Their prevention requires, for example, a reliable colour reproduction, avoiding artificial colour dominants in photographs, and eliminating reflections.

Most of existing approaches, nowadays, use multi-image photogrammetry, but differ in the acquisition method: in the case of the digitization of the Byzantine Mosaics of the Nativity Church (Doria, Picchio, 2020) were used images acquired by hand or with a tripod; otherwise, for the documentation of an archaeological site, the camera was mounted on a pole (Fazio et al., 2019); and, when possible, the images were acquired directly from a drone (Caldeira et al., 2019). All these researches focused on the geometric acquisition or the high-resolution to obtain a highly resolute texture, but the influence of ambient light and light reflections effects were not tackled, as, mostly, the floorings were outdoors.

Moving forward to the necessity of high-resolution radiometric image acquisition: during an in depth analysis of previous researches, (Wells et al., 2005) stood out, as they tried to combine color selectivity and coaxial aligned polarization. This research provided the highest glint rejection and highest signal-to-noise ratio. They worked on single test object, a very reflective sphere, but performed their trials in a laboratory. Similarly, another research team (Conen et al., 2018) worked with polarized light to reduce reflections and improving image matching, but the object and its scale and location are dealing with laboratory conditions.

Literature highlights that the cross-polarization technique is already widely used in other disciplines such as medical diagnostics (Hanlon, 2018) or geoscience (Apopei et al., 2021), whereas in the field of Cultural Heritage there are not very many experiments and (above all) the application cases are quite different. In fact, the technique of cross polarization has been used for cultural objects such as historic globes (Menna et al., 2012), pottery (Guidi et al., 2014) or other art-objects (Guillaume et al., 2020). These experiments were laboratory applications where the object to be documented was very small and at the same time it was possible to maintain well-defined lighting conditions throughout the survey. As documented by these articles, the use of cross-polarization technique was exploited to perform photogrammetric acquisitions on objects that have glints, but that never reach the scale of a floor.

This paper presents a prototype designed to obtain a high-resolution digital survey of floors (even very large ones), which aimed to avoid the aforementioned problems of reflections, and improved the efficiency of the acquisition. Specifically, here the cross-polarization method was implemented inside a sort of isolated and closed but "movable" environment, in order to eliminate any reflection caused by ambient and environmental lights on the reflective surfaces of interest (e.g. marble floors). In section 2, the general topic of floor survey is described, followed by a discussion on the acquisition system and its specific components. The discussion starts from the needs and the choices made to realize the prototype, and focuses especially on the principles, both from a geometric point of view and from

a qualitative point of view. Then, in sections 3 and 4, first applications are presented and the preliminary results discussed. Finally, section 5 concludes the article with a focus on future developments and adjustments of the prototype.

2. METHOD

2.1 The concept

Multi-image digital photogrammetry systems have already demonstrated their versatility and the numerous advantages they bring in the documentation of cultural heritage. These methods, however, require special attention when the result wanted (i.e., digital surface model, or orthomosaic) must be of very high-resolution and precision. In these cases, it is not possible to rely solely on data processing software, but it is necessary to work carefully on the data acquisition phase itself, in order to grant a correct result.

As already mentioned, there are two types of difficulty in acquiring data: the geometric and the qualitative one. The geometric difficulties are related to the very high-resolution required for these documentation projects. To obtain 1:1 or 1:2 scale representations of a floor, the GSD must be very small and, more importantly, as constant as possible. These two conditions are obtained by maintaining a constant acquiring distance (correctly calculated during the design phase of the survey) and above all by using photographs captured at an angle orthogonal (nadiral) to the floor. The latter suggested practice (apart from the obvious variations due to the average scale of the photograms) allows a consistent and constant GSD, which is not the case with inclined photographs. These acquisition conditions can be enforced in different ways, for example, by systems that uses a crane to keep the camera always nadiral (through a special gimbal) or a drone. However, it is not always possible, in historical indoor environments, to move around with large and cumbersome instruments or with flying objects, because of the difficulty of moving them around and of the presence, as often happens, of tourists and other people on the acquisition site. Therefore, it arises the need to design a mobile structure conceived specifically for this use, such as described in the next paragraph. This prototype includes a cart on wheels to which the photographic acquisition system can be attached; in this way the orthogonality between the camera and the floor is granted.

From a qualitative point of view, the difficulties are mainly related to the management of colour and reflections. When the radiometric characterisation of stone and marble becomes fundamental information for the subsequent phases of study and design, it is not possible to rely only on ambient light. It is necessary to use an artificial lighting system that can be calibrated and that is, as far as possible, isolated from the environment in which it operates. But the more important obstacle, in this contexts, is the second, the presence of reflections. In fact, the floors that typically require high-resolution documentation consist of stone, marble, and sometimes even glass materials (mosaic tiles). Each of these materials has its own behaviour under the light. In the photogrammetric field, it is not easy to manage the different behaviours of the materials surveyed. The reflections of marble, for example, can be a problem in the image alignment phase (because the algorithms do not recognise points with different reflections as homologous). They also certainly constitute a problem in the characterisation of the material which, with reflections, can take on different colours.

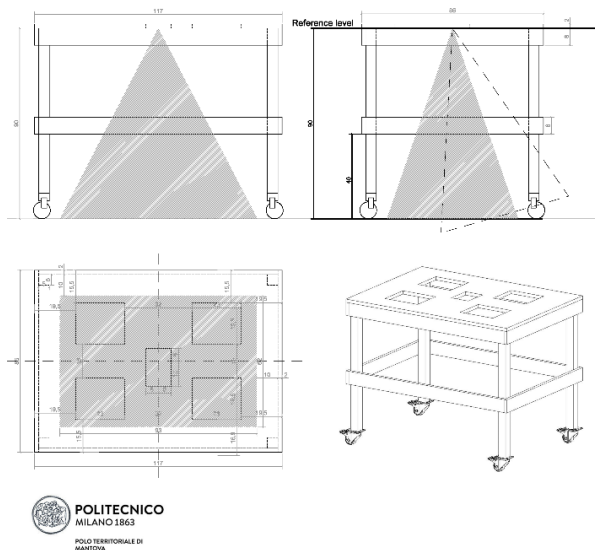


Figure 1. technical drawings of the cart. The starting dimension for the design is the height from the reference level of the camera system, set to guarantee a constant known GSD dimension. The grey area is the cone of view of the digital camera, and the dashed line in the transversal section (upper right) represents the possibility of small camera tilting. The height of the reinforcement bars in the bottom of the cart depends on the rotation of camera acquisition.



Figure 2. the acquisition prototype in its first release with the light system, the camera and the laptop for on-site photo verification

To overcome this obstacle, the photographic technique of cross-polarization was chosen. Cross-polarisation occurs when two polarising filters are placed with a 90 degree relative angle. This technique starts with a first linear polarizer which transmits one axis of polarization. After the first filter, light passes through a second polariser. When the two polarising filters are parallel there is maximum light transmission; but when they are orthogonal the transmission is minimal and almost all reflections are eliminated.

2.2 The prototype and its use

The acquisition system has been designed according to different goals and methods, described in Table 1.

Goal	Method
diffuse and constant light	creation of an “isolated” environment
stable camera position with respect to the floor	enablement of only minimal rotation/translation
avoidance of reflections	cross-polarization technique
colour reliability	use of color calibration system
movable system	independent cart

Table 1: goals for the prototype and proposed solution

The result of the design stage is the prototype in Figure 1 and Figure 2. The design of the prototype started by considering the camera system (camera and lenses) for photographic acquisition and the average scale of pictures. As the goal was to obtain a very high-resolution orthophoto, we set the goal of a 0.1 mm GSD.

We decided to use a Canon 5DSR (sensor size 36 x 24 mm, image dimension 8688 x 5792 pixels) with 35 mm lenses. In order to have the desired GSD, according to photogrammetric theory, the distance from the object could be computed, and in this case should be about 850 mm (0.850 m). This first value was the first parameter to be considered in order to guarantee the geometric correctness of the prototype. This value also determines the field of view for each photograph: in fact, if we consider the floor to be comparable to a plane, the area photographed is about 0.9 x 0.6 m, and depends on the height of the prototype, the camera, and the lens. We decided to mount the camera, by means of a ball camera head, on a vertical bar, to have the possibility of making small variations in the main distance to modify the GSD, if necessary. In addition, the use of this ball head allowed slight tilting of the camera to reach the edges of the area included in the carriage. This feature has been very useful to take pictures of the border of the floor.

Moving on to the lighting system, we defined a homogenous set of lights using 4 LED Video Lights with a dimmable system between 3200-5600K, for Studio Portrait. They were equipped with a battery charger, but (for this experiment) it was decided to use direct power supply, to avoid problems with battery life. On the same cart, it was also necessary to power the laptop and the camera system. For this reason the prototype was equipped with a power extension cable, in order to allow free movements in the surveyed area, while being connected to electricity. The 4 spotlights were positioned symmetrically in order to have a ground illumination as constant as possible. Diffusers were used to overcome the effects of glare, thus avoiding the problem of light spots on the images. However, even though the direct glare from the headlights was reduced to a minimum, all reflections still remained. To implement the cross-polarisation system described above, it was therefore necessary to use two sets of polarising filters, one for the camera and one for the light sources. The NISI Natural CPL PRO Nano polarizing filter was mounted on the Canon EF 35mm f/2 IS USM lens. For each light source, a polarising film, size A4, was placed directly over the diffusers so that there would be no further interference.

The last step in setting the lighting conditions is the isolation from the outside. This was achieved empirically by using a heavy cloth, neutral in colour, to cover the whole cart up to the ground. With all these arrangements, the space under the trolley results isolated from the outside and can be illuminated as required, independently of the outside. In the various tests carried out, this

has been a great advantage as it has made it possible to work in areas of direct light with strong shadows, but also during evening and night-time hours, when the colour of the fixed lamps in the surrounding environment would have turned the result yellow. This also made it possible to have a stable condition over time, making it easier to set up a well-defined procedure for the acquisition.

In order to further facilitate the survey operations, it was decided to connect, as anticipated, the power supplies to the cart, to avoid the use of batteries (for lights, camera and laptop). Finally, it was decided to use a direct laptop-camera connection to shoot directly from the laptop (by the software DigiCamControl) and view the acquired image on a larger monitor (14 inches). In fact, it may not be always easy to check the quality of the images from the LCD screen of the camera and postponing the operation until the end of the work could be very risky. For this reason it was chosen to use the laptop, where it was possible to check, for each captured photo, the quality and the possible presence of unwanted elements (dirt, cables, etc.). Finally, the system was equipped with wheels to facilitate moving on uneven floors and the transport of the cart itself.

This prototype tries to respond not only to technical problems but it aims to be an effective tool for the acquisition procedures of the floor. The possibility of working at any time of day, of not necessarily having to isolate large floor areas (instead, only those in which the cart is operating), while avoiding the need to set up photographic sets, are great advantages with respect to operating conditions. The only obstacle, which is solvable in most architectural surveys, is the need to bring electricity to the cart, after which the system is autonomous and independent. Together with the physical prototype, it has been necessary to set a list of procedures and actions in order to guarantee the best results for the digital image acquisition. The workflow is composed by the following steps, in terms of actions to perform:

1. check all video and electrical connections;
2. check the light settings (all lights with the same colour temperature of 56000K and maximum intensity 100%);
3. check polarising filters orientation;
4. set the acquisition of .raw and .jpg pictures;
5. acquire the first pictures with a colour calibration system;
6. set longitudinal and transverse displacements.

Some points of the checklist are evident and only served as a procedural reminder. For others, it is necessary to provide a little more information.

Point 3 (the orientation of the polarising filters) is one of the most important operations because it is essential that the two polarising filters used (on the lens and on the headlamps) have a relative rotation of 90°; only thus the reduction of reflections could be correctly obtained. It has not been possible, however, to make this variable (the rotation angle) fixed over time because whenever the camera was removed from the system and repositioned in its bag, the polarising filter was removed. It was therefore preferred to establish, in the procedure, the step of checking the orientation angle. The operation was carried out, empirically, by observing the variation of the reflections through the monitor of the laptop connected to the camera. Since this effect has a sinusoidal trend, linked to minimum values of 0° (both filters with the same direction) and maximum values of 90° (filters in a direction orthogonal to each other), it is easy to monitor the effect by manually rotating the filter and stopping at

the moment of maximal reduction of reflections. Afterwards, the established orientation of the two filters must not be changed during the entire photo capture session.

Another important step is the one related to colour, point 5. It is very difficult to achieve on-site the same accuracy in overall lighting conditions control as in a lab, but the best method is to use a known radiometric reference in the shots. Therefore, by using the Xrite Colorchecker Passport 2 (card and software) calibration system, it is possible (during post processing) to modify pictures by defining a specific colour space, which remains valid for all the images captured in the photo session. This is the reason why we chose, as described in point 4, to capture all photographs in raw format. The same radiometric corrections can be made on all photographs of the same acquisition session.

The final step towards guarantee of a correct result (in this case according to geometric aspects) is related to photograph overlaps and, consequently, to longitudinal and transverse displacements of the prototype. The uniquely established height for the camera makes it very easy to calculate the value of the displacements; by imposing an overlap, in both directions, of 70%, which, for the abovementioned characteristics of the prototype, means about 0.30 m displacement in longitudinal direction and about 0.2 m transversal. These values imply that each point is visible in at least 4 or 5 photographs, which should grant a successful result of the photogrammetric process. In addition, the strong overlap in the two directions, longitudinal and transverse, allows the photogrammetric model to be stiffened.

The photogrammetric survey, made with the prototype, is a very efficient solution to guarantee the geometric quality of the outcome and a good correspondence between the radiometric value of the picture and the real one. Anyways, to complete the entire process, a topographic approach to define Ground Control Points (GCP) is still necessary to scale the model and to define a reference system for the whole work.

3. FIRST TESTS DESCRIPTION

The application of the prototype on a real case study had two goals. First, a validation of the principle of cross polarization for the trustworthy image acquisition of historical floors. Second, the validation of the whole process in terms of geometry, final radiometric quality, and final products that could be extracted from this photogrammetric process.

3.1 Image acquisition of reflective floors

The image acquisition through the designed prototype was focused on eliminating all the environmental reflections that are often a major obstacle in this type of works. The system has been tested on different types of floor so that different conditions related to diverse materials and surfaces could be experimented.

The first tests were performed, at the beginning, in the university building where the prototype was developed: a floor consisting of modern tiles, light and homogeneous in colour, very glossy and reflective. Then, further tests were performed again in the university rooms, on a typical 1960s floor consisting of black and white grit.

After the first trials, used mainly to assemble correctly and build the prototype, further tests were carried out on two different cultural assets and, for them, the entire process (from the acquisition to the orthomosaic generation) was implemented. For



Figure 3. The Sala degli Arazzi and its floor. This picture puts in evidence some obstacles for the survey: the presence of strong light from the window, the reflection of the pavement together with the obstacles present in the room and the decay of the floor

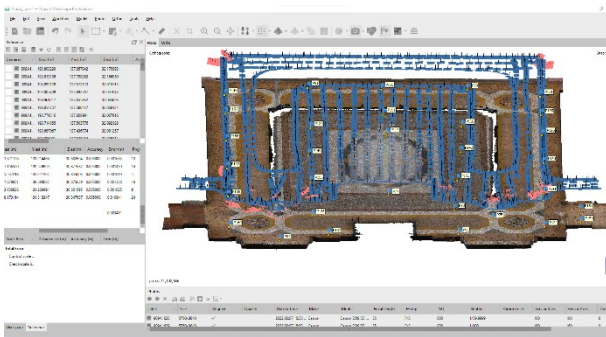


Figure 4 screenshot of the Metashape project with the position of targets, the pictures (in red the ones acquired manually) and the dense point-cloud.

the purpose of this paper, it is sufficient to recall the type of floor tested: a first one made of stone slabs of different materials, colour, state of preservation and conservation status and a second one made of traditional “battuto veneziano” better described in the next paragraph.

3.2 Case study: the floors of the Sala degli Arazzi in Palazzo Ducale, Mantova

The complete test of the system was conducted on one of the Sala degli Arazzi (Tapestry Rooms) of the Palazzo Ducale in Mantova (Figure 3). The room is part of a group of four rooms re-furnished at the end of the eighteenth century to host Raffaello's wall tapestries (about 1550 A.D.), which were restored by the superintendent of Palazzo Ducale starting in 1776. The architectural project was designed by Paolo Pozzo, while the decoration was planned and carried out by Felice Campi, who created the first neoclassical decorative campaign in the Ducal Palace (mantovaduale.benculturali, 2022). For the four rooms he created floors in "battuto veneziano", a technique typical of the Triveneto area, according to which floors are made of marble and stone granules with a diameter of up to 40 mm, held together by lime mortar (or cement) mixed with fine grit and fine “cocciopesto”, with a diameter of up to 5 mm. The floor is then completed with a wax finish that makes it shiny and reflective. This room was chosen because its floor has issues related to conservation and restoration that can be well documented through a high-resolution survey of the floor.

The entire survey was carried out over three hours, including both the positioning of the photogrammetric targets and their measurement by total station. Unfortunately, it was not possible to remove the metal structure housing the tapestry lighting apparatus, so there are some gaps in the final model.

First of all, the coded targets extracted from Agisoft Metashape were printed in a suitable size, positioned at an average distance of about 2 metres, following a fairly regular grid. It should be noted that some targets were unintentionally lost during the photo acquisition operations because they were fixed in a way to be easily removed, to not ruin the floor. The cart system was set up on site, positioning the lights, the camera and the laptop. The operations were planned and carried out using the checklist described in Section 2.2 so as to have a GSD size of about 0.1 mm and a very good radiometric quality of the images.

A total of 1434 photographs were taken to survey the entire (ca 50m²) floor. Only 124 of them were taken while holding the camera manually, in order to capture the zones that could not be reached with the prototype (a better description is in Section 4.2). The photographs, acquired in Canon's proprietary raw format (.cr2) were all converted into the colour space defined using the Xrite Passport checker 2 system software.

Subsequently, according to the consolidated photogrammetric process; these steps followed: image orientation at high quality, automatic target recognition and optimisation of the parameters (to obtain a more precise description of the internal orientation of the camera). Then, the photogrammetric model was georeferenced and scaled with the coordinates measured with topography. This was followed by the creation of the dense cloud (low quality, to obtain 11 millions point), the triangulation of the points and the construction of the mesh, textured with an 8192 x 8192 pixel square image (Figure 4).

The last step was the creation of the orthophoto: the average pixel size proposed by the software was 0.17085 mm, but it was considered more correct to compute the orthophoto with a pixel size of 0.5 mm, to take into account any possible errors.

4. DISCUSSION ON PRELIMINARY RESULTS

4.1 Image acquisition

The first results regarding photographic acquisition are very encouraging. Figure 5 shows the difference between the image acquired without the cross-polarisation technique (top) and that obtained using the cart prototype (bottom). It is evident that in the second image there is much less reflection, which allows to better recognize each material. Initial tests have shown that the most difficult elements to reproduce faithfully are dark coloured stones and marbles, where the effects of reflections tend to be more evident.

These reflections might create problems in the photogrammetric orientation phase (especially considering that the images take up a small portion of the floor) and, above all, might not allow for a correct identification and subsequent characterisation of the material.

Although the reflections have been correctly removed, unfortunately, there are side effects that need to be further investigated. In Figure 6, four haloes of blue-tinged colour can be seen, albeit with difficulty. These four areas correspond to the artificial headlights and are most evident on dark materials. Initial tests have shown that they do not depend on either light intensity

or light colour. Attempts were also made to change the orientation of the filters, without obtaining any significant effect.



Figure 5: comparison between images acquired without (top) and with (bottom) the acquisition system. The differences are evident especially on the black marble where all the reflections are deleted and the stones appear completely black

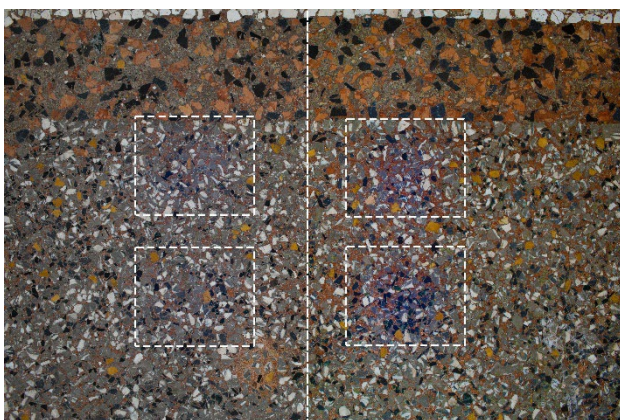


Figure 6: picture with the four blue-tinged areas, corresponding to the headlights, characterised by a colour tending towards blue. The image (original in the left-hand side) has been modified in the right-hand side to highlight the effect.

Further studies should be made to detect the source of the blue halo and remove it. To the best of our knowledge, there is still no in depth research, especially regarding these practical operational aspects.

This effect, which, as already stated is more pronounced on dark materials, almost disappears in orthophotos, but only because the software Metashape blends the colours among the many pixels describing the same point. The four areas with a reflection tending towards blue are corresponding to the position of the lights: they remain fixed in the image, but since the cart moves, they affect different portions of the floor: the algorithm, by using several images to define the colour of the orthophoto, manages to smooth out this effect, which is hardly noticeable in the overall final image.

4.2 Overall survey.

For the entire floor survey, the results obtained confirm the good operability of the proposed system.

Looking first of all at the acquisition operations, it can be noticed that the prototype makes it possible to optimise the process in favour of a correct acquisition of geometry. According to the test, the workflow described in Section 2.2 could be implemented with these three further step:

- 1.- 6.(see par. 2.2)
7. photographic acquisition using nadiral-axis camera strips;
8. photographic acquisition of the perimeter through a single strip with a slightly inclined axis camera;
9. acquisition with a hand-held camera.

Step 7 constitutes the main acquisition phase and is done with the camera mounted on the prototype in a nadiral axis and using the displacements calculated previously. At this stage most of the frames were acquired in this way.

Step 8 consists of a single strip of photographs along the perimeter of the floor. The purpose of this acquisition phase is to stiffen the system along the borders and also to capture the edges between the floor and the vertical surface (wall). To do so, it is necessary to tilt the axis of the camera slightly (see the dotted line in Figure 1, upper right), which allows the most peripheral part of the prototype to be framed in the photographs. The pixel variation is very small and therefore does not create errors in the final product.

The third phase, 9, was necessary to overcome the impossibility of acquiring some specific cases linked, above all, to concave angles where the cart cannot access (as evident from Figure 7). This limitation was easily overcome by taking a few photographs holding the camera manually, but it was not possible to apply the cross-polarisation technique due to the difficulty of isolating the areas from external lights. However, those areas were generally very small (as can be seen from the diagram in Figure 4) and in most cases the effects are not noticeable.

To assess the quality of the survey of the floor, apart from the well-known workflow in Agisoft Metashape, attention was focused on the indicators that explain the quality of the work and in particular the point-cloud confidence (Farella et al., 2012): it is intended as the number of contributing combined depth maps to set the points. This value, that is generally used for the further filtering of the point-cloud, is also a parameter of quality, as the points defined by higher number of depth maps are the more accurate. In the case study, the majority of points is green (Figure 8) and it means that such points have been defined by at least five images. The yellow points are located mostly in the area of the metal structure in the center of the room, that covered the lighting system for the tapestries. Of course, this value is not strictly related to the prototype cart (as it depends on the configuration

of strips acquisition) but it can be optimised, using the cart, by setting precisely the displacement and setting a temporary grid on the floor, for example, by tape.

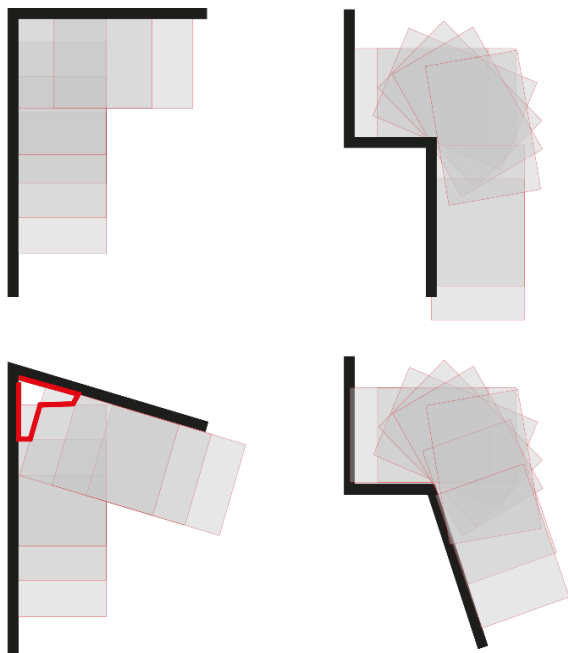


Figure 7. different behaviour of the prototype in the acquisition of convex and concave corners. The most complex is the case of convex corner (bottom left) where the size of the cart doesn't allow to reach each part of the corner.

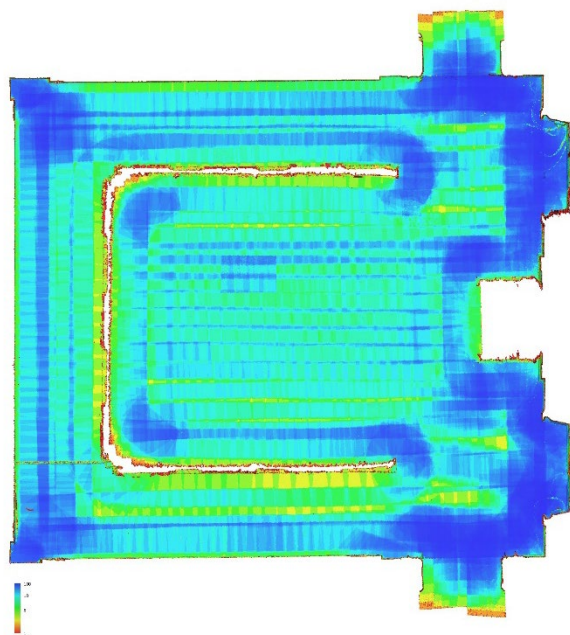


Figure 8. statistical analysis of the photogrammetric model of the survey: the dense point-cloud confidence, with values between 1 (red) and 100 (blue)

The following georeferencing and scaling was done through targets automatically detected by the software. It should be noted that two targets (out of 22) were lost during the survey operations, as the wheels of the prototype shifted and thus rendered the two targets unusable. The coordinates of targets were acquired by total station and, after the roto-traslation, the resulting average error (3 mm) is of the same order of magnitude of the accuracy of the total station. This confirms that the photogrammetric model is well-structured.

The last check was done on the orthophoto (see a detail in Figure 9). According to the setting of the prototype, the pixel size for the orthophoto (projected on the generic plane XY) has been computed by the software as 0.00017 mm, but the orthophotomosaic has been realised with a pixel size of 0.5 mm in order to avoid possible approximations due to the software. The photographic quality is very high, and the small blue haloes described above are not visible.

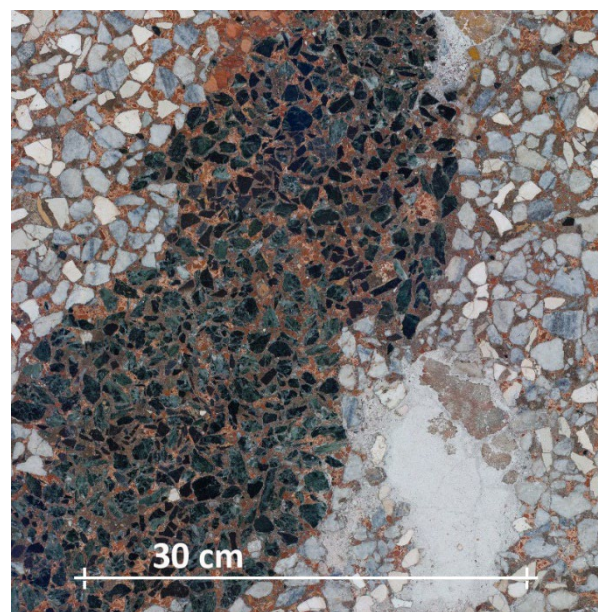


Figure 9. detail of the orthophoto, where the single elements of the "battuto veneziano" are evident, together with the small cracks and the decay of the floor. The pixel size is 0.5 mm.

5. CONCLUSIONS

The high-resolution survey of historical floors is a topic of great interest as it allows the more in-depth analysis that a marble or mosaic surface and their conservation require over time. The prototype described in this article -still in its experimental phase- aims to respond to the need of optimising such surveys, by paying equal attention to the geometric and radiometric aspect of the floor surface. As far as the geometric aspect is concerned, setting the photographic camera at a fixed height allows to have great homogeneity of data, both in the initial captured images and in the final results. The geometry of acquisition quality is then achieved by carefully setting the longitudinal and transverse overlap to determine a rigid and stable model.

Attention to the photographic acquisition quality, especially colour and illumination, was instead addressed by adopting the technique of cross-polarisation with the aim of eliminating all

reflections and having a high correspondence between the acquired colour and the real one. In order to obtain an environment suitable for this technique, the prototype described created a space isolated from the environmental lighting. This made it possible to make the acquisition phases more operational by being able, in fact, to work in any light condition.

The prototype, tested for the moment on modern floors and on some cultural assets, needs some in-depth studies. The first topic is linked to determine the source of the blue halo effects, and how to remove them. The development of the prototype has so far focused on functionality, but in the future it is planned to develop the structure in a more efficient way. In fact, it is currently made of wood, but other materials could also be employed, also considering the possibility of assembly and disassembly, to facilitate its transportability, and possible shipment.

REFERENCES

- Apopei A.I., Buzgar N., Buzatu A., Maftai A. E., Apostoae L., 2021: Digital 3d models of minerals and rocks in a nutshell: enhancing scientific, learning, and cultural heritage environments in geosciences by using cross-polarized light Photogrammetry. *Carpathian Journal Of Earth And Environmental Sciences*, Vol. 16, No. 1, P. 237 – 249; Doi:10.26471/Cjees/2021/016/170
- Caldeira, B., Oliveira, R.J., Teixidó, T., Borges, J.F., Henriques, R., Carneiro, A., Peña, J.A., 2019: Studying the construction of floor mosaics in the Roman Villa of Pisões (Portugal) using noninvasive methods: High-resolution 3D GPR and photogrammetry. *Remote Sens*. Vol. 11.
- Conen, N., Hastedt, H., Kahmen, O., and Luhmann, T., 2018: Improving image matching by reducing surface reflections using polarising filter techniques, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2, 267–274, <https://doi.org/10.5194/isprs-archives-XLII-2-267-2018>, 2018.
- Doria E., Picchio F., 2020: Techniques for Mosaics Documentation through Photogrammetry Data Acquisition. The Byzantine Mosaics of the Nativity Church. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci* 2020, 5, 965–972
- Farella E.M., Torresani A., Remondino F., 2012: Refining the joint 3D processing of terrestrial and UAV images using quality measures. *Remote Sens*. Vol. 12, 1–26.
- Fazio, L., Lo Brutto, M., Dardanelli, G., 2019: Survey and virtual reconstruction of ancient roman floors in an archaeological context. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, Vol. 42, 511–518.
- Fregonese L., Monti C., Monti G., Taffurelli L., 2006: The St. Mark's Basilica pavement: the digital orthophoto 3D realisation to the real scale 1:1 for the modelling and the conservative restoration. In: Abdul-Rahman A, Zlatanova S, Coors V (eds) *Innovations in 3D geo-information systems. Lecture notes in geoinformation and cartography*. Springer, Berlin, Heidelberg, pp 683–693;
- Guillaume H.-L., Schenkel A., Clerbois B. Trémouroux S., 2020: Good Choice of Photogrammetric Approaches during the same Mission. Ways of Saint James in Namur. *Proceedings of the International Conference on Cultural Heritage and New Technologies* in Vienna.
- Godin, G., Rioux, M., Levoy, M., Courmoyer, L., Blais, F., 2001: An Assessment of Laser Range Measurement of Marble Surfaces. *Proceedings of the 5th Conference on Optical 3-D Measurement Techniques*, Vienna, Austria, 49-56
- Guidi G., Gonizzi Barsanti S., Micoli L., 2014: Image pre-processing for optimizing automated photogrammetric performance. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci*, volume II-5, 2014. ISPRS technical symposium, 23–25 June 2014, Riva del Garda, Italy. p. 145–52.
- Hanlon K. L., 2018: Cross-polarised and parallel-polarised light: Viewing and photography for examination and documentation of biological materials in medicine and forensics, *Journal of Visual Communication in Medicine*, 41:1, 3-8, DOI: 10.1080/17453054.2018.1420418
- Mantovaduale.beniculturali, 2022: Le stanze degli Arazzi: un intervento di fine Settecento, Retrieved March 2022, from <https://www.mantovaduale.beniculturali.it/it/news/500-le-stanze-degli-arazzi-un-intervento-di-fine-settecento>
- Menna F, Rizzi A, Nocerino E, Remondino F, Gruen A., 2012: High resolution 3D modelling of the Behaim globe. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*, volume XXXIX-B5, 2012, XXII ISPRS congress, 25 August–01 September 2012, Melbourne, Australia. p. 115–20.
- Wells, J., Jones, T., Danehy, P., 2005: Polarization and Color Filtering Applied to Enhance Photogrammetric Measurements of Reflective Surfaces. *Proceedings of the 46th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference; American Institute of Aeronautics and Astronautics: Reston, Virginia*, Vol. 7, pp. 1–7.