RENDERING EQUIRECTANGULAR PROJECTIONS ACQUIRED WITH LOW-COST 360° CAMERAS

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ABSTRACT:

A workflow for editing and rendering 360° images (also called spherical or equirectangular images) is illustrated and discussed. The aim was to develop a novel procedure able to overcome limitations induced by deformations in images acquired with low-cost 360° cameras. Editing and rendering are carried on equirectangular projections using a dynamic procedure that turns images into traditional central perspectives, enabling the user to change viewing directions, modify digital content, and store the changes in the original files. Integration of the rendered projections with traditional outputs of digital recording operations as well as other deliverables of the architectural restoration project is also discussed. Finally, the development of a web-GIS application that stores and shares multiple deliverables (including the newly proposed renders) is presented.

1. INTRODUCTION

Nowadays, the acquisition of 360° images and videos is a relatively simple and rapid task that can be carried out with various low-cost digital cameras, which capture the entire scene around the photographer. Images and videos can then be shared on the web using different services such as YouTube, Mapillary, Twitter, Facebook, Kuula, Roundme, or 360cities.net. Specific software packages are available to create panoramic tours in which information can be added using texts, photographs, or hyperlinks, among others.

This work aims at using 360° images and videos beyond traditional sharing and visualization purposes. Although the acquisition of 360° photographs is a powerful solution for rapid inspection and documentation of historic buildings and sites, the proposed work tries to integrate additional information by digitally editing image content. Indeed, editing tools for 360° images are integrated into a few commercial software packages (such as PhotoShop or Affinity Editor), overcoming the limitations concerning equirectangular mapping, i.e., the projection used to store such images and videos. 360° image painting is also becoming more popular. An example is PanoPainter, available for MAC OSX, iOS, Windows, and Android.

The paper focuses on rendered 360° images integrated into a web-GIS platform with more traditional deliverables produced using digital recording tools. The web app provides simplified access to an alternative way to generate architectural renders. The overall structure of the implemented platform is shown in Figure 1. The platform uses geospatial information to provide access to the original and rendered images and 360° videos for rapid understating of the actual conditions of the site.

As mentioned, the proposed workflow differs from traditional 2D and 3D architectural rendering for the use of equirectangular projections taken with low-cost 360° cameras. Architectural renders are often used in different projects to provide a photorealist visualization of the designed interventions and changes. 2D rendering is usually carried out on traditional photographs, which can be interactively modified with different software to create new synthetic views from a fixed angle. 3D rendering is usually more labor-intensive, but it overcomes the limitations of fixed viewing directions.

The case of rendering based on equirectangular projections proposed in this paper is at an intermediate level between 2D and 3D rendering. The work is not only 2D because visualization is provided under an angle of 360°. However, it cannot be considered a complete 3D solution because no 3D model is available unless a photogrammetric project based on multiple projections is run, which is beyond the scope of this work. One of the main advantages of the proposed rendered equirectangular projections is the opportunity to create an immersive visualization covering a 360° field of view. This makes such kind of novel rendering very attractive for the opportunity to simulate interventions and visualize results in a 360° context with a rotating point of view.

It is worth mentioning that 360° images can also be used for photogrammetric reconstructions. A set of images captured with a low-cost panoramic camera can be processed with some commercial software (e.g., Agisoft Metashape, Pix4Dcapture), in which the spherical camera model replaces the more traditional frame-based (pinhole) camera model. Different papers described the pros and cons of photogrammetric models generated from 360° images. The reader is referred to Aghayaria et al. (2017), Abate et al. (2017), Barazzetti et al. (2015;2017), Fangi (2017), Fassi et al. (2019)., Kwiatek et al. (2014-2015), Matzen et al. (2017), Strecha et al. (2015). However, the aim of this paper is not a 3D modeling workflow. The authors intend to show how equirectangular projections can be rendered, integrated, and shared along with other deliverables from a digital recording.

2. CASE STUDY AND PROJECT FRAMEWORK

The aim is to develop a novel digital twin of a site using a combination of cartographic data, digital data acquired on site with digital recording tools (e.g., laser scanning, photogrammetry), as

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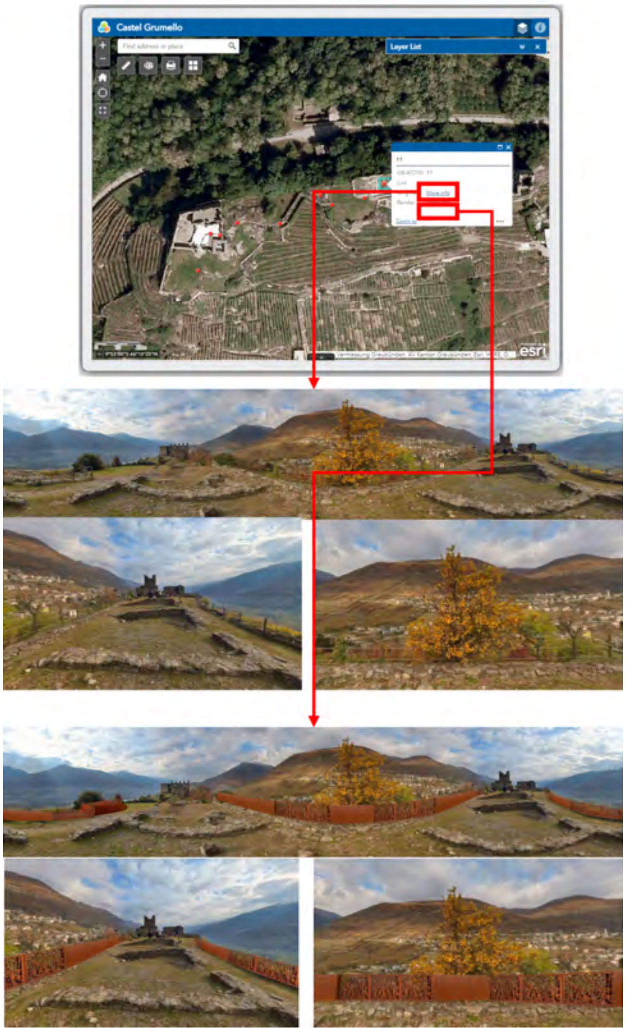

Figure 1: The web-GIS applications with both links to original and rendered equirectangular projection.

well as alternative forms of data visualization coupled with the more traditional outputs of a geometric survey. For this reason, the implemented workflow is based on equirectangular projection because they can provide immersive visualizations showing both the actual condition of a site and the planned interventions exploiting the rendering procedure proposed in this paper. Such digital outputs are integrated into a web-GIS platform using a point shapefile incorporating both the location and a link to the images.

The case study proposed in the paper is Castel Grumello (Figure 2), a rare example of a twin castle in the municipality of Montagna in Valtellina, Italy. Figure 2 shows the site, which includes two castles that had different functions. The west wing was the residential area, whereas the east part was a defensive structure.

The castle is a property of FAI (Fondo Ambiente Italiano), which carried out restoration works at the end of the '90s.

Activities were carried out in the framework of innovative teaching methods at Politecnico di Milano. The aim was to develop novel forms of data capture and processing to support the creation of digital twins in architectural restoration courses.

The proposed method goes beyond traditional data processing methods for the use of rendered equirectangular projections integrated into a web-GIS. At the same time, the typical deliverables (CAD drawings, orthophotos, 3D models etc.) can also be integrated into the web-GIS.

Figure 2: The case study used to try out the proposed method, Castel Grumello in Valtellina (Italy).

As mentioned, the method is currently applied during an architectural restoration course at Politecnico di Milano. The aim was to develop novel alternative ways of digital representation during the entire workflow of an architectural restoration project: digital recording, material / constructive technologies and condition mapping, intervention, reuse, and valorization projects. Special attention was paid to a procedure allowing students to directly operate using low-cost hardware and software in a limited time framework.

3. RENDERING EQUIRECTANGULAR PROJECTIONS

Equirectangular projections feature 2:1 width/height (w/h) ratio, corresponding to 360° horizontal and 180° vertical field of view. Figure 3 shows the mapping grid pattern, in which vertical lines (meridians) remain straight vertical lines, whereas horizontal lines (parallels) are progressively distorted towards the poles. Equations relating pixel coordinates (x, y) and angles expressed as complement of latitude (ϕ) and longitude (λ) are rather simple: $x = r\lambda$ and $y = r\phi$. The radius of the sphere r (in pixels) can be estimated as $r = h/\pi$ and it corresponds to the focal length (in metric unit) of the 360° camera (Fangi, 2009; 2017; Pisa et al., 2010).

Editing such images is more complicated than traditional photo-editing based on traditional photographs. The user must face additional geometric (mapping) deformations beyond traditional perspective effects. The proposed solution is a rendering protocol for equirectangular projections, which are temporarily converted into standard distortion-free perspectives. Indeed, the user can change the viewing direction in the traditional bubble visualization, apply editing and rendering operations, and store the results on the original equirectangular projection considering the required mapping. The approach is dynamic because the point of view can be changed multiple times.

Figure 4 shows an example of a ramp digitally added in an equirectangular projection. The idea was to replace existing stairs with a structure that provides facilitated accessibility in the castle. Simulating the proposed ramp on the original image only took 15 minutes of manual work, which consisted of retouching the equirectangular projection after its preliminary local conversion into a traditional central distortion-free perspective image.

As can be seen, the ramp becomes a curved geometry in the

equirectangular projection, but the proposed rendering method allows the user to render it as a regular central perspective.
Then, the use of the 360° image provides a better immersive level compared to static photographs, as shown in Figure 5. The user can also turn the visualization and better perceive the entire area with the new element. The achieved result is useful when the added elements cannot be represented by a single (central perspective) image. The user can rotate the bubble visualization to get a virtual view of the entire area around the photographer.

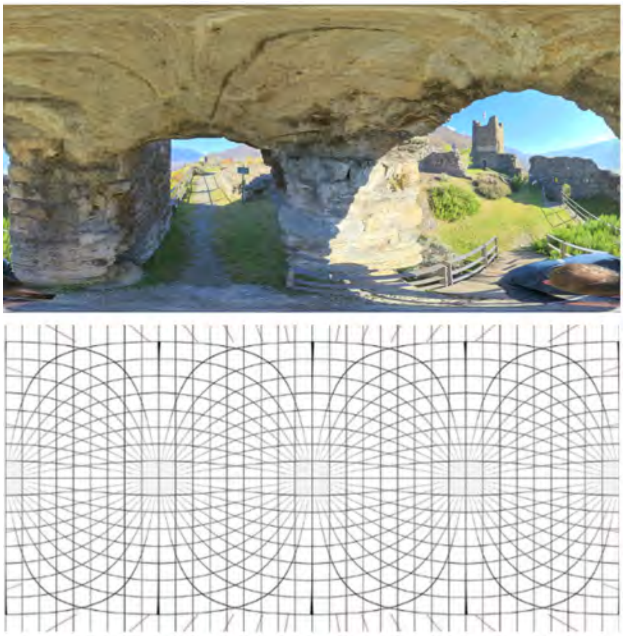

Figure 3: 360° image visualized as equirectangular projection (top), and the deformed grid pattern of horizontal and vertical lines (bottom).

Figure 4: Top: Original equirectangular protection acquired with a low-cost 360° camera (Insta360 One R). Bottom: rendered result in which a ramp was added in the center of the image to replace existing stairs.

Figure 5: The equirectangular projection visualized as a central perspective with a bubble visualization, showing the original stairs (top) and the digitally added ramp (bottom).

4. MORE ON EQUIRECTANGULAR PROJECTION EDITING, VISUALIZATION, AND SHARING

4.1 Overall considerations

Shown in Figure 6 is another example of rendering in which corten steel barriers and totems were simulated. Figure 7 shows a detail of both images. The original image was acquired with an Insta 360 One R. Rendering with the proposed procedure required less than an hour, which is a significantly shorter time than 3D rendering based on a 3D model, which would require significant time and effort to create a complete 3D model. The immersive visualization visible in Figure 8 allows the user to understand

and perceive changes after the addition of elements, not only limited to the area of the castle but also how the new elements are inserted into the landscape.

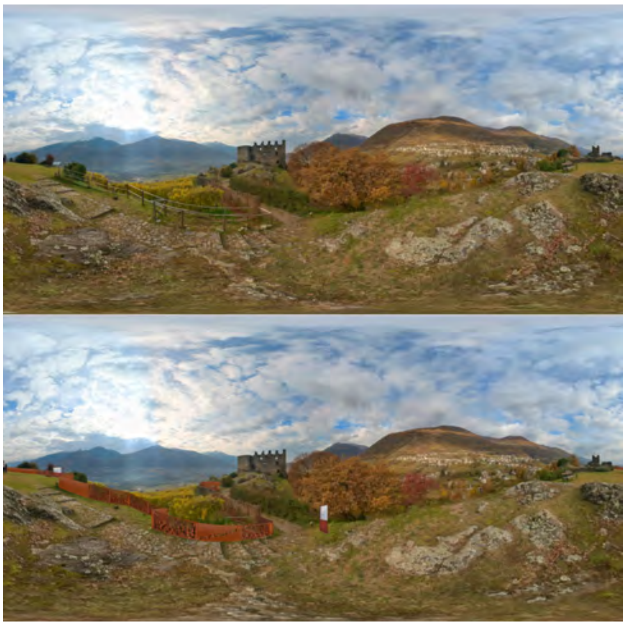

Figure 6: The original equirectangular projection (on top) and the generated rendered projection. As can be seen, straight elements become curved entities in the equirectangular projection.

Figure 7: A detail extracted from the previous image. As can be seen, straight lines become curved elements in the equirectangular projection, making direct rendering of such images a complicated task.

4.2 Integrating other deliverables in the rendered projection: an alternative form of visualization

Shown in Figure 9 is another type of rendering, which is carried out by combining equirectangular projections with technical drawings on vertical surfaces. The idea behind this representation is the integration of equirectangular projection together with traditional deliverables produced in digital documentation projects. Figure 9 (top) shows the equirectangular projection with a CAD elevation (manually traced), which was overlapped using the proposed procedure. The image in the middle shows the same projection using a bubble view visualization, offering alternative deliverables in between a CAD drawing and immersive visualization. Finally, the last image (bottom) shows deterioration (condition assessment map) using hatches re-projected on the equirectangular projection. Mario E. Viale, Francesco Villella, Nasko Stefanov Voynov, Emanuele D. M. Zanini Vallin produced these deliverables in a CAD environment.

Figure 8: Bubble-views of both original and rendered equirectangular projections.

Figure 9: Examples of 2D CAD deliverables projected onto the equirectangular projection: CAD elevation (middle) and condition assessment map (bottom). The image on top shows the original equirectangular projection with the CAD elevation.

4.3 Implementation of a web-GIS application for data sharing and visualization

A web-GIS application was developed to integrate equirectangular projection with several other deliverables from digital recording using photogrammetry and laser scanning. The web app provides direct access to specific georeferenced deliverables (maps, orthophotos, digital terrain, or surface models) and simplified access to other data. The app can be accessed using a PC as well as mobile phones and tablets (Figure 10).

In the case of equirectangular projections, they were added as point shapefiles. The attribute table contains links to bubble-based visualizations, including the original (unedited) projections and rendered images. The point itself instead provides information on the location.

The castle was also documented using laser scanning and digital photogrammetry. Orthophotos and digital surface models were created using a drone, obtaining visual supports to generate site plans. Laser scans were acquired with a Faro Focus S70. Georeferencing was carried out through GNSS techniques using an Emlid Reach RS2 receiver connected to the network station available in the area (SPIN3 GNSS). The project was created in the system UTM32-WGS84 ETRF2000-RDN, 2008.0. Ellipsoid elevation values were converted into orthometric values using the Italian Geoid model ITALGEO2005. The use of the current Italian reference system is here intended not only as a possible choice for the project. The aim was to register the data in the current version of the reference system adopted in Italy, which is based on a specific geoid model (ITALGEO2005) and the reference system ETRF2000-RDN (2008.0). Although several commercial software can provide global models (such as EGM96 for correcting ellipsoid elevation), it is fundamental to use the convention in the country to ensure reliable results.

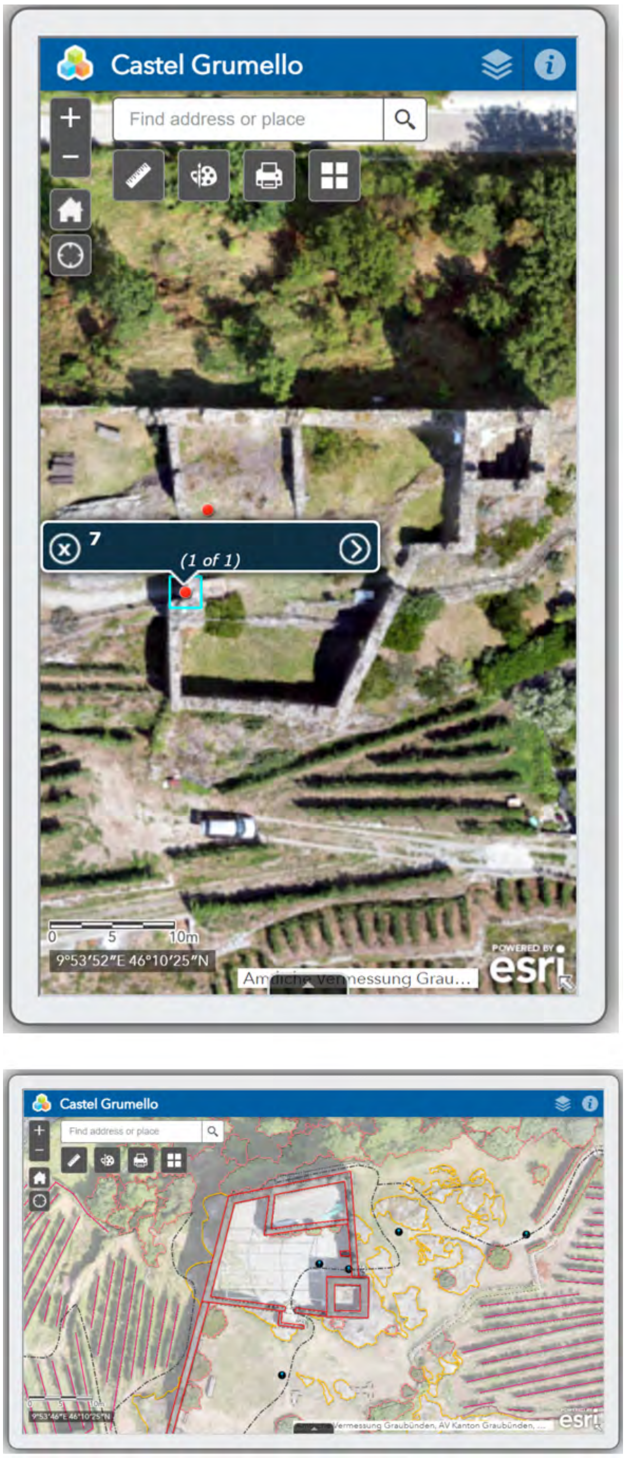

Figure 10: The developed web-GIS app (top) with icons to access the different layers of the rendered equirectangular projections.

Figure 11: Examples of different datasets accessible using the GIS webapp.

The webGIS application was generated considering both geospatial information available in the area (i.e., GIS information at regional and provincial level) and local information acquired on site. Data can be summarized as follows:

- ESRI shapefiles of buildings, roads, and contour lines at the provincial level (layers retrieved from online repositories);
- aerial orthophoto at regional level produced with a photogrammetric survey (retrieved from online repositories);
- orthophoto produced using a drone (featuring high resolution);
- site plan produced in CAD and converted into a georeferenced image;
- high-resolution digital elevation model from the drone (the layer can be used to obtain accurate orthometric elevations);
- different layers generated starting from the produced CAD and converted into shapefiles considering the different elements: wall, face, stair, rock, path, vegetation, etc.;
- point shapefile indicating the spatial location of equirectangular projection, with links to original and rendered images shared on the cloud; hapefile indicating the trajectory during the acquisition of 360° videos, with links to the videos shared on the cloud.

Figure 12: The 2012 orthoimage and some vector layers produced in the project.

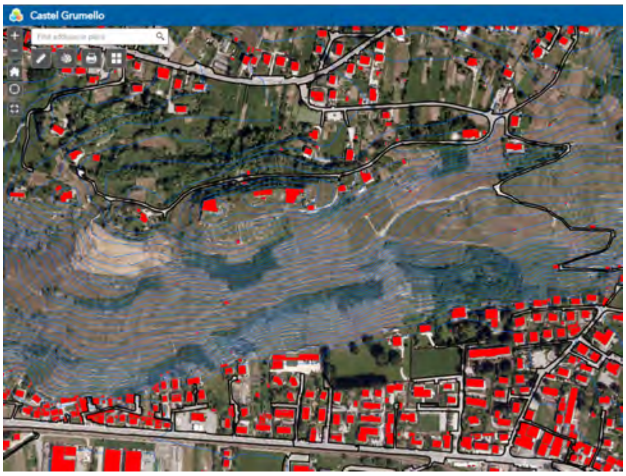

Figure 13: An overview of the area with some shapefile at territorial scale loaded into the web app.

More deliverable will be added in future work. Shown in Figure 11 is an example of visualization using Chrome. The image on the top shows a part of the surveyed area and the site plan converted into a georeferenced raster. The second image (middle) shows the same area with different items imported as vector layers, which can be inspected and customized in the app. The image has a different background based on a high-resolution orthophoto from a survey with a drone (GSD at centimeter level). Images were photogrammetrically processed together with a set of ground control points measured with a GNSS receiver. The CAD drawing used for producing the GIS shapefile was generated in the framework of teaching activities by Elena Conti, Sara Cosentino, Ottavia De Martino, and Elena Ricca. CAD layers were turned into a set of different GIS shapefiles.
The last images (Figures 12 and 13) show a larger area with the orthophoto at the regional level produced in 2012. Shapefiles were also integrated. The web application can therefore integrate multi-scale digital data. Automatic tiling of high-resolution datasets was added to obtain real-time visualization, especially in the case of high-resolution images produced with the drone.

5. CONCLUSIONS

The paper presented a rendering procedure based on 360° images, termed equirectangular, spherical, or latitude-longitude projections. This kind of image can be captured with 360° low-cost cameras and provide an immersive visualization under a 360° field of view, which is much larger than the traditional representation based on frame (central perspective, pinhole) images.

The paper aimed to develop and test a rendering procedure that can overcome the limitations induced by equirectangular mapping, in which cartographic deformations would prevent the use of these images in rendering processes. The proposed procedure allows one to turn the projection into a typical pinhole image. Therefore, the user can use normal editing operations, which are saved considering their deformations on the equiectangular projection and applied to the original projection. Rendering is carried out by changing the field of view to replicate the same procedure for the entire image.

Such digital tools can be helpful in a preventive verification of the results of an architectural preservation project. This is the case when new use or enhancement of the site requires new elements. These modalities cannot replace traditional project documents, which result from a rigorous path of knowledge. In other words, they can be intended as a useful integration of traditional deliverables.

A web-GIS application was also developed to provide access to the different deliverables produced in the project. The original equirectangular projections and rendered versions can be accessed using point shapefiles. The attribute table contains the links to the different images stored on cloud services. Additional outputs (orthophotos, DEMs, etc.) are also available.

Future work consists of testing the proposed procedure with students to verify the feasibility of the proposed approach. In this way, the authors aim at stimulating a novel form of rending that is not based on traditional 2D images or 3D models.

6. ACKNOWLEDGEMENTS

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