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3D VISUALIZATION OF INTERIORS – THE CASE OF "U JAKSY" GALLERY

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Summary

Many generations have tried to represent the surrounding space, often striving to do so in the most accurate way, precisely reflecting details and shapes. An important step towards the faithful representation of reality was the creation of photography. Over time, the two-dimensional spatial imaging became insufficient, forcing the creator to choose the appropriate perspective and a comprehensive, holistic view of the object. It became possible to recreate the third dimension using two-dimensional photographs, e.g. by creating a stereogram, a panorama, or developing a 3D model. Techniques related to 3D modelling have become a very important element of contemporary photogrammetry, and they allow for an interesting, effective, and metrically accurate manner of depicting reality. 3D models can be used for the inventory of objects, for their reconstruction, and for their presentation. Today, there is a great need to represent the world around us in the digital space, starting from selling products whose 3D models make it possible to see that product from every side, to the creation of three-dimensional maps with street views, such as Google street view, to creating virtual city and museum walks. The products of 3D graphics are not only used for visual effects. The models' metric accuracy also enables numerous engineering applications. Among other things, 3D models can be used in geodesy for inventory measurements, they find their application in architecture and spatial planning, as well as in many other engineering activities related to the designing of parts, machines, and objects.

Keywords

non-metric cameras • 3D models • visualization

1. Introduction

A 3D model is a mathematical representation of an object in three dimensions. Objects are visually represented using a set of points in three-dimensional space, connected by various geometric figures such as triangles, lines, plane curves, etc. After creating the model, the most common textures are applied thereto, defining the details of the object's surface, or its colour [Takaaki and Yasuhito 1992].

In recent years, modern photogrammetric technologies have found a broad range of applications in recreating 3D models of buildings. Mainly, the measurement data obtained as a result of their application are used to model their external parts. However, throughout the world there is a growing interest in spatial data obtained also from the buildings' interiors, which shall complement the external models obtained in the past. The resulting 3D models constitute an abundant source of information that can be used for measurement, cognitive, or analytical purposes, as well as for the creation of architectural objects. Particularly noteworthy are the analytical capabilities of virtual models that allow for a simulation of changes or phenomena that cannot be analysed in a real-life setting [Lee et al. 2008]. Obtaining correct imaging of rooms is a key stage in any elaboration of short-range photogrammetry. The way in which this imaging is performed depends on the size and shape of the object to be measured. The method of convergent multi-image network is the best method for developing a visual representation of interiors. The choice of this method is conditioned by the need to develop representations of various types of rooms and their elements. Acquiring images with the use of this particular method should be based on the general-to-detail principle. In the first stage, all rooms should be subjected to imaging, and then similar images of individual groups of elements should be taken [Kraszewski and Brodowska 2014].

Replacing optical close-range cameras with digital cameras, mainly non-metric ones, allowed for a wider development of geodesy in the field of stereophotogrammetry. However, in order to fully reflect the desired effect and afford the possibility for the elaboration of further studies, these cameras must be distinguished by high mechanical precision and possess appropriate optical conditions. Desktop analysis has become highly automated. In order to obtain automatic determination of the coordinates of a given point, it is necessary to determine the coordinates of a series of points by specifying the centroid, the centres of the circles, or the corner of the disc. Measurement of a single image obtained from a digital camera consists in software recognizing, adjusting, and then indicating the point described, according to the given pattern [Bujakiewicz et al. 2011].

Non-metric cameras can be used in either aerial or ground photogrammetry. The method of using the camera, however, depends on the technical requirements to be met by the developed model. If we need to obtain a fully metric object using a non-metric camera for photogrammetric purposes, we should calibrate the camera for a given shooting distance before beginning the measurement process, and use a fixed lens that ensures repeatability of the elements of internal orientation, which shall allow us to develop elaborations using, for instance, digital stereoplotters. Thanks to the above, the "3D models of objects obtained by the application of photogrammetric methods are characterized by high accuracy and detail of representation, in contrast to the models created with the aid of generally accessible, easy-to-use online software". However, the application of a specific method, as well as tools making it possible to obtain such a model should be dictated primarily by that model's intended purpose, although the costs of the study often play an important role as well" [Kwoczyńska and Rzepka 2013]. The use of non-metric cameras without calibration also allows us to create models – albeit of lower quality, but developed in a shorter time, and with the currently offered resolutions and sizes of non-metric camera sensors, it also facilitates obtaining the proper metric accuracy of such a model. Digital photogrammetric systems for image data processing are compatible with CAD/GIS and are jointly used to create relational databases [Nour el Din and Grussenmeyer 2000].

Three-dimensional models of buildings, structures or elements of landscape architecture created on the basis of the images find numerous applications. A particularly significant field for their use is architecture and urban planning, in which spatial imaging of objects makes it possible to develop an accurate survey and present its results in an attractive way. "The use of three-dimensional techniques to visualize architectural objects has become the basis for various architectural and planning studies and has been used for this purpose for many years". A 3D model of the object makes it possible to visualise the properties and features of the tested object. Showing the object in the third dimension allows architects to develop a complete survey of often complex and sometimes also poorly accessible architectural objects. Obtaining information about such objects can be achieved by a variety of methods. Three-dimensional models of cities are created mainly on the basis of data obtained from aerial photogrammetry, and such models can be developed on the basis of stereograms of aerial images, from clouds of point obtained from laser scanning. These data can be extended with information obtained from terrestrial mobile scanning, or by using terrestrial photogrammetry techniques. The said models play an important role in contemporary spatial planning, in tourism, or in various issues related to the management of urban areas. "The usefulness of 3D city models in many areas is enormous. The visualized spatial map provides geodetic spatial data and assists in the management of a city. Designers and architects use 3D models, for instance to fit new buildings into the existing built environment. At the same time, 3D models are applied in education and tourism. 3D models can also be used, among others, for the preparation of planning studies (studies of the conditions and directions of spatial development) and projects of local spatial development plans, for planning and designing new investment projects, for simulating natural disasters, to assist management in emergency situations, for developing acoustic maps, for monument protection, for telecommunications projects, for creating location services, and in traffic navigation systems. 3D models are also used in environmental protection, to create maps of possible spread of pollution" [Kwoczyńska et al. 2009].

2. Study area

In the present publication, an attempt was made to generate a photorealistic three-dimensional model of one of the rooms of the art gallery – "U Jaksy" BWA (art exhibitions office) Gallery in Miechów. The gallery has a historic character due to its location in the cellars, which are the oldest architectural feature of the former monastery complex of the Holy Sepulchre. The cellars are built of rough stone and Gothic brick, forming the shape of an elongated rectangle, with a barrel vault and a cut cylinder ceiling.

In the central part, there is a connecting point with a characteristic pentagonal shape, dividing the space into two rooms. In both rooms, exhibition screens are mounted on the longitudinal walls (Fig. 1). Spotlights are attached to the vault, arranged in two rows, allowing the exhibited works to be highlighted.

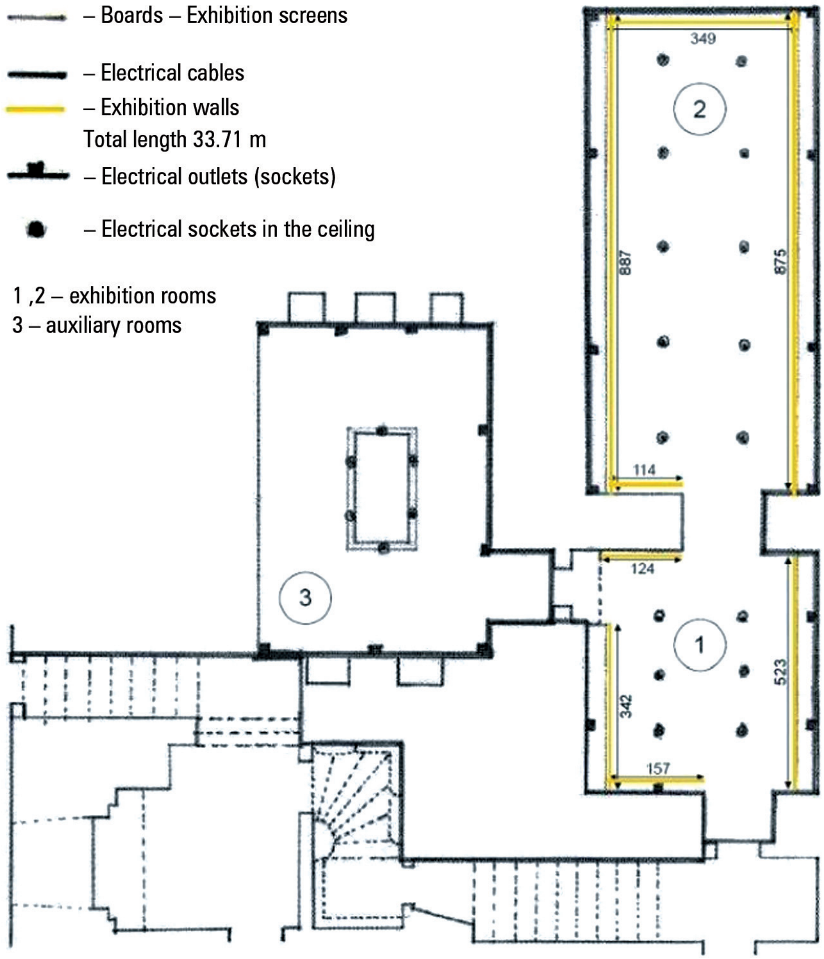

Fig. 1. Plan of the "U Jaksy" Gallery in Miechów

3. Methodology

The following kit was used to achieve the intended objective: Nikon D7200 camera, with Nikkor AF-P lens, 10–20 mm, f/4.5–5.6G VR. The set was mounted on a level tripod. By shifting the tripod by a distance that ensured adequate coverage between the photographs, images were taken in two series from a height of 116 cm, and 144 cm. When taking the photographs of the longer walls, the camera was positioned as close as possible to the wall opposite to the photographed one. The lower series encompassed the floor and the wall above the exhibition boards within the field of the photograph, while the upper series had been framed in such a way as to include the exhibition wall and the vault. Due to the shape of the room, the transverse dimensions of which make it necessary to shoot close-up and include as much space within the image field as possible, the 10 mm focal length was used. With the application of this focal length, the angle of view for the camera used was 109°. The photos were taken in a vertical orientation (Fig. 2 and 3).

In order to reflect the character of the room, the photos were taken with the regular lighting provided in the gallery. This is spotlighting directed at the exhibited works, whereas individual light sources are mounted in two rows under the vault. This system of lighting gives relatively little light, which made it difficult to achieve proper exposure of the photographs taken. Due to the small amount of light available in the room, but also due to the need to obtain a large depth of field to take the photographs, the following exposure parameters were set: f/6.3 aperture, shutter speed 1/80 s, while the ISO sensitivity was selected using an automatic program that typically introduced the value of 3200. Photographs were taken in the manual mode, and the exposure time was set as the longest possible that would allow the pictures taken not to be blurry. Although the photographs were taken from a tripod, it produced little stability. The exposure was corrected using the ISO sensitivity parameter, whereas the camera used allows taking images free of noise even at high sensitivity values. The photos were taken in the JPEG format in the "normal" (regular) quality, i.e. with an average level of compression, at dimensions of 6000 × 4000 px and a resolution of 24 million px. Due to the need to

Fig. 2. Sample photograph from the lower series

Fig. 3. Sample photograph from the upper series

maintain the continuity of images in the corners of the room, diagonal photographs were taken, connecting the supporting wall, and the short wall – the transverse wall. The camera was moved obliquely in relation to the wall, and after taking a series of oblique photos, when the camera was in a position parallel to the shorter wall, photos were taken in a series parallel to the shorter wall, and then another diagonal series was taken to return to a position parallel to the longer wall. The photos were taken in closed loops, separately for each room, first in the lower series, and then, after completing the entire loop, in the upper series.

3.1. Development of the obtained data

The development of the 3D model was performed using the Agisoft software application, and it consisted of four basic stages: importing the images, orientation of the photographs, creating a sparse point cloud, generating a dense point cloud, and creating a 3D model. The finished 3D model can be scaled, and based on the photographs, a texture can be created that enhances the visual effect of the model's presentation. The first stage of work in the software application was uploading 448 images, compressed to JPEG format.

The next step in creating the model is the orientation of the photographic image in space. The software finds common points in the photographs and adjusts them to each other. In its further processes, the program uses the recreated position of the photographs to build the model. At this stage, a sparse point cloud is also generated, which is not used in the subsequent stages of model creation, but it only represents the result of matching the photographs. On the basis of the sparse point cloud, a region is created representing the volume for which further processing will be conducted. At this stage, we need to check if the region was generated correctly and, if necessary, to adjust the region for which a dense cloud of points and 3D models will be created. It is also possible to change the orientation of the region, to change its dimensions, or to move it to the desired location using the "Resize Region", "Move Region", and "Rotate Region" tools (Fig. 4).

The third stage of model elaboration is generating a dense point cloud, from which 3D models are developed directly. After the dense cloud has been created, it can be edited in the process of cleaning the cloud of points, in which erroneously generated or unnecessary points, e.g. points from the surroundings, are removed. The dense cloud was cleared of points generated outside the area of the rooms that had been rendered (Fig. 5 and 6).

The fourth stage of the work is to recreate the geometry of the model by creating a continuous representation of the surface. Based on the created dense cloud of points, the metashape reconstructs the surfaces of the modelled object, creating a polygon grid. This grid consists of three-dimensional polygons, where two surface representations of the model are also created in the process.

The final step in creating the model is texturing. It is a technique used in three-dimensional graphics that makes it possible to better visualize surface details

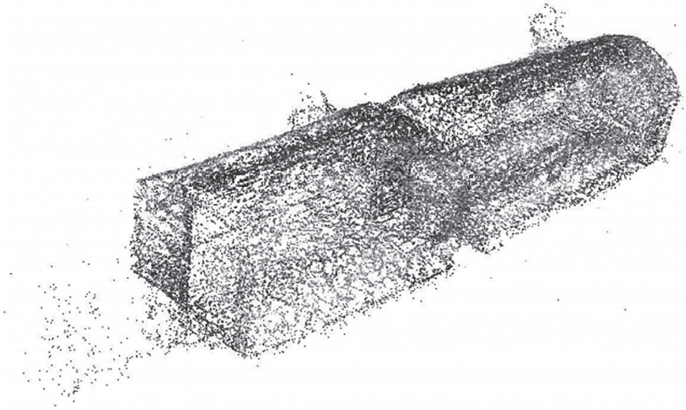

Fig. 4. The generated sparse cloud of points

Fig. 5. View of the dense cloud of points – room one

Fig. 6. View of the dense cloud of points – room two

and render real colours. The effect is achieved by means of spatial bitmap images, the so-called textures obtained on the basis of photographs or generated with the application of mathematical functions. In this technique, image pixels are associated with the surface of the modelled object. After creating the model, in order to give it a photorealistic look and obtain a greater level of detail, the texturing process was performed (Fig. 7 and 8).

After the model was developed, in order to give it an appropriate scale, the dimensioning process was initiated. The dimensions were adjusted on the basis of the image

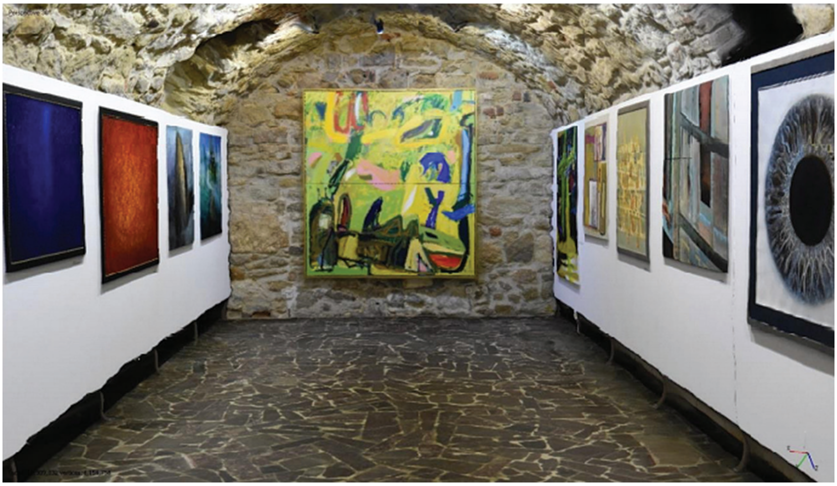

Fig. 7. Textured 3D model

Fig. 8. Textured 3D model, the view of the link between the rooms

frames determined during the measurements, as well as the room dimensions obtained from the building plans. The process of assigning measures takes place by fixing the "markers" on individual images, then lines are created from the appropriate markers – the so called "scale bars", which should be assigned appropriate lengths by entering them in the "distance" column (Table 1).

Table 1. Dimensioning with the application of the Agisoft Metashape software

Markers	X [m]	Y [m]	Z [m]	Accuracy [m]	Error [m]	Projections	Error [pix]
point 4	–18.990450	42.768177	–25.589213	0.005000	14.703905	76	0.000
point 5	–7.428535	37.268418	–13.444005	0.005000	0.012857	80	0.000
point 6	–7.468059	37.834718	–13.104578	0.005000	0.012306	78	0.000
point 7	–7.135100	37.547730	–12.612098	0.005000	0.017919	70	0.000
point 8	–7.102005	36.978348	–12.950436	0.005000	0.018414	62	0.000

Total Error

Scale Bars	Distance [m]	Accuracy [m]	Error [m]
point7_point8	0.670000	**0.010000**	0.001322
point5_point6	0.670000	**0.010000**	–0.000432
point6_point7	0.670000	**0.010000**	–0.001740
point1_point2	1.220000	**0.010000**	0.016838
point3_point4	1.220000	**0.010000**	0.011823
point2_point3	1.220000	**0.010000**	0.016448

Total Error

As a result, after refreshing the file, a scaled model was obtained with the accuracy down to a few centimetres. The effects of scaling can be checked with the measure tool. A sample measure to check the length of the board in the gallery plan is 887 cm, with the dimension in the model being 891 cm (Fig. 9).

After completing the work on the model, it was extracted into an .obj file, which facilitates its playback or reproduction in other software applications (Fig. 10).

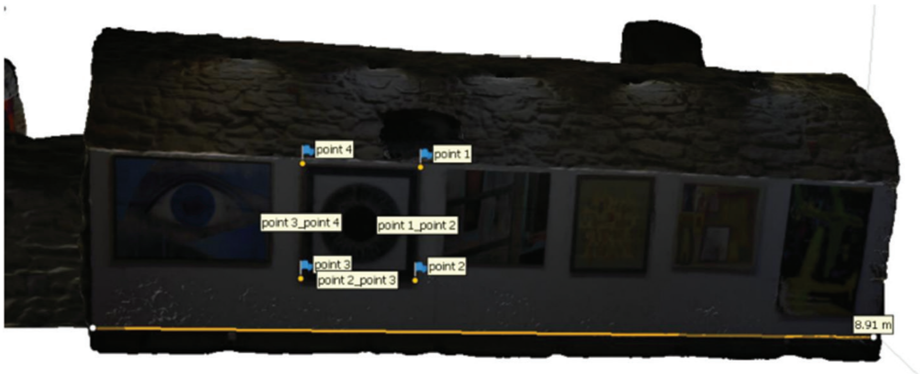

Fig. 9. Measurement of the object

Fig. 10. View of the model in the Microsoft "3D viewer" application

4. Study results

The aim of the study was to create a 3D model that reflects the character of the exhibition space of the "U Jaksy" Gallery as realistically as possible. The model satisfactorily reflects the shape, the dimensions, and the colours of the room and the artworks displayed within it. The only visible error, which could potentially be eliminated by increasing the quality of the rendition, is seen in the undulating lower edges of the boards, or in some of the picture frames (Fig. 11).

Accessible equipment was used to develop the model: the Nikon d7200 camera, with a Nikkor 10-20 zoom lens. Due to the constancy of internal orientation elements, photogrammetric studies typically use fixed focal length lenses, for which the camera's parameters are determined at a fixed shooting distance, due to the change of the focal length during focusing. Because of the conditions in the room, i.e. the insufficient lighting and

Fig. 11. Visible distortions of exhibits

the elongated shape, it was not possible to calibrate the camera for one, fixed shooting distance. Nevertheless, all the photos taken were used to create the model. Due to the computer’s conversion capabilities, photos with dimensions of 6000x4000 px were taken in the medium quality offered by the camera, and saved in a compressed JPEG format, which significantly reduced their quality, but which still enabled further processing.

4.1. Comparison of the developed model with a “virtual walk”

At the beginning of June 2020, the “U Jaksy” art exhibition institution published a “virtual walk” online. The latter had been developed by Agencja Interaktywna 360, using the technique of panoramic photography. The space that is the subject of the present study was also featured in the virtual walk. For the purposes of the online tour, high-quality spherical panoramic images depicting the exhibition space of the gallery were developed. Spherical panoramas are created by photographing the surrounding space from one position, while making a full circle around it. Then the images are combined using the computer software specifically designed for the purpose. The layout of the photos resembles a sphere, and the individual photographs have to maintain appropriate coverage relative to one another. As a result, an image is obtained that can be freely rotated and zoomed around one point. For interior rendering, this is most often the central point, in the middle of the given room. When comparing the resolution of the model developed as part of this study (Fig. 12) with the resolution of the spherical panorama (Fig. 13), we observe that the 3D model renders much worse results, because the final visual effect is obtained in the texturing process. On the other hand, the virtual tour offers a resolution, which is close to that of a photograph.

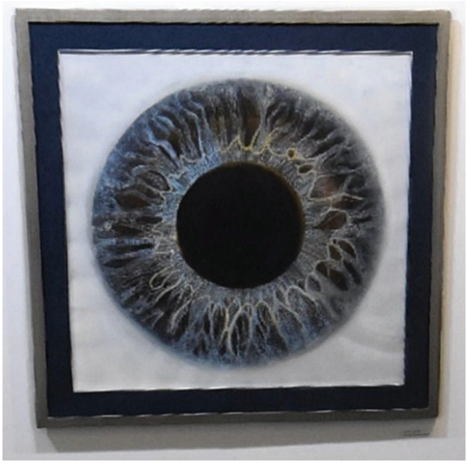

Fig. 12. Exhibited work by Paweł Olchawa represented in the 3D model

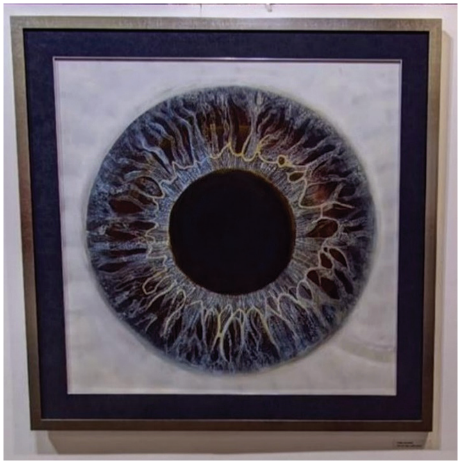

Fig. 13. Exhibited work by Paweł Olchawa represented in the virtual walk

In the case of the virtual walk, thanks to the higher resolution, the image has been visually represented with a greater degree of detail. Compared to the 3D model, we can capture more details of the exhibited works, and also their colours have been more faithfully reproduced. On the other hand, the 3D model allows the viewer to freely move around the object, to zoom in and out at any point without changing the aspect ratio. Then again, spherical photographs that use incorrect approximations and perspectives will cause disproportionate changes in the sizes of the rooms and the exhibited paintings (Fig. 14 and 15). Rotation around one point does not facilitate the observation of all the exhibits from a parallel perspective.

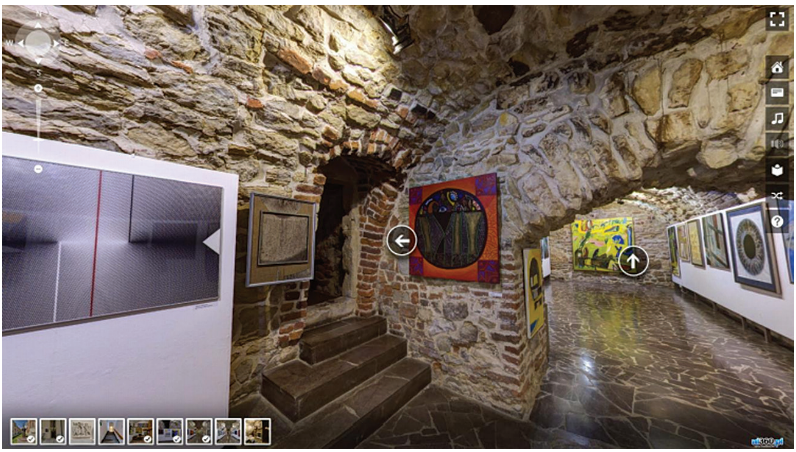

Fig. 14. Virtual walk – errors of perspective

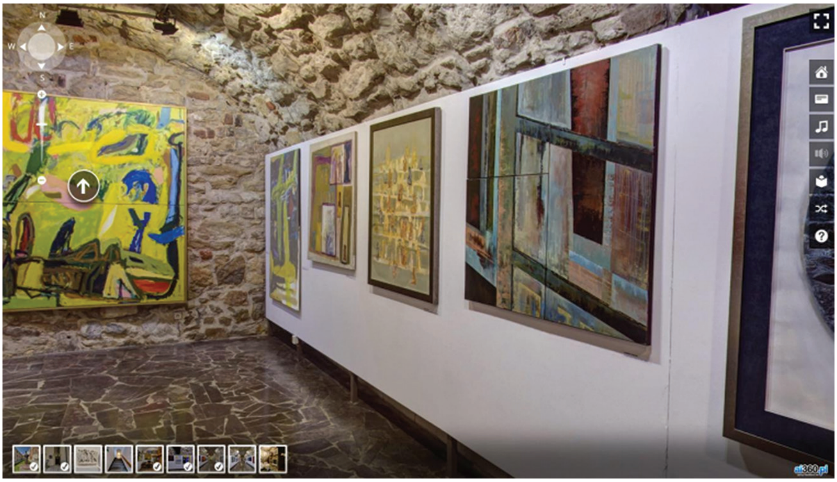

Fig. 15. Virtual walk – lack of option to view all works at the same time

The virtual walk is burdened with only those kinds of distortions, which result from perspective. Conversely, the 3D model is additionally burdened with distortions caused by errors in the development process.

5. Conclusion

When comparing the two techniques of visual representation of space, it can be concluded that both forms, despite their minor flaws in representing reality, render the interiors of the "U Jaksy" Gallery in an interesting and aesthetically sound way. Despite its poor quality, the 3D model can be used as an attractive "virtual walk", in particular because it allows the viewer to freely move around the object. The model's errors are mainly due to the poor quality of the equipment used in the process of its development. By using a higher resolution of photographs, as well as by rendering individual works within the model in a higher quality, it will be possible to obtain an effective, interesting, and metrically accurate way of representing the object.

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