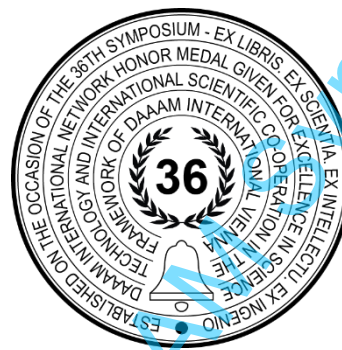


SPHERICAL PANORAMIC PHOTOGRAPHY, VIRTUAL TOURS AND THEIR USE IN CRIME SCENE INVESTIGATION

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Abstract

Spherical panoramic photography and virtual tours offer a comprehensive and accessible method for documenting crime scenes. This article provides an overview of this technology and its applicability in forensic practice. It outlines the historical development of panoramic photography, describes the panoramic projections used for spherical images, and compares the main types of imaging equipment—ranging from robotic, motorized, and manual panoramic heads to integrated 360° cameras and mobile phones. Selected software for image stitching and virtual tour creation is also characterized. Furthermore, the article addresses digital data integrity during processing, including the impact of stitching, blending, and hotspot insertion on image metadata, as well as the use of checksums to ensure record authenticity. Practical experience shows that virtual tours require relatively affordable equipment and involve short on-site capture times; they can serve as a valuable supplementary tool for crime scene documentation, law enforcement training, and building security assessments, while original photographic documentation remains the primary evidence.

Keywords: photography; panorama; virtual tour; space; software; crime scene; data integrity.

1. Introduction

Documenting a crime scene is a fundamental step in any crime scene examination. The documentation must capture not only individual pieces of evidence but also their spatial relationships, as the examination process itself inevitably alters the scene, making it impossible to restore it to its original state. Traditional documentation methods—such as written reports, sketches, standard photography, and video recordings—remain the standard in practice. However, a photograph depicts only a limited portion of the scene, requiring the observer to mentally reconstruct the spatial context.

In recent years, significant attention has been focused on the virtualization of real-world environments and its application in forensic practice. Ševčík and Adámek [1] reviewed methods suitable for the virtual reconstruction of crime scenarios, specifically photogrammetry, 3D laser scanning (LiDAR), RGB-D mapping, and 3D game engines. To evaluate these methods, they proposed four criteria: speed of 3D reconstruction, level of visual authenticity, processing complexity, and scalability/versatility. They also highlighted the pivotal role of visual representation in crime scene reconstruction and noted that a static environment suffices for presenting 3D digital evidence. Spherical panoramic photography

combined with a virtual tour offers precisely such a static yet visually authentic representation; although the authors mentioned this approach in their review, they did not evaluate it alongside the other reconstruction methods. Compared to laser scanning or photogrammetric modeling, this method requires relatively affordable equipment and minimal time for on-site data acquisition; furthermore, the final output can be viewed in a standard web browser without the need for specialized software.

Virtual environments are significant not only for documentation but also for professional training. Martirosov and Kopeček [2] conducted a literature review on the impact of virtual reality on training and education. This aspect is particularly important for security forces, enabling them to use virtual representations of real-world locations to prepare for operations and practice procedures under realistic conditions.

This article therefore outlines the historical development of panoramic photography, the panoramic projections employed, the techniques and equipment used to capture spherical panoramas, and the software used for image stitching and virtual tour creation. Finally, it discusses potential applications of virtual tours in crime scene investigation, security force training, and building safety assessment.

2. A brief history of panoramic photography

One method to better display the captured scene (crime scene) is panoramic photography. This is a photographic genre that usually captures a wide-angle view, most often of a landscape or another whole. This is a relatively old method, with one of the first patents for a panoramic camera dating back to 1843 and coming from the Austrian Joseph Puchberger [3]. His camera recorded a field of view with an angle of 150° and a focal length of 8" on daguerreotype plates measuring 19 to 24". Of course, this was not a spherical panorama, but a cylindrical panorama. This is mainly due to the practical possibility of outputting this type of photography. These first panoramic photographs, of course, are displayed in a classic form - i.e., on paper or photographic plates. These individual parts of the panoramic image were then stacked next to each other, and after assembly a finished panoramic image was created.



Fig. 1. 1851 San Francisco from Rincon Hill by photographer Martin Behrman [4]

In the second half of the 19th century, various camera manufacturers attempted to build a device that would allow the capture of space in a horizontal plane with a maximum range of 360° . This was only achieved by Rudolph Stirn in 1889, when he took the first 360-degree panorama with a camera called the "Wonder Panoramic Camera". Another milestone in the field of panoramic photography is the turn of the 19th and 20th centuries, when, around 1900, the first panoramic cameras appeared on the market. An example of this is the Al-Vista 3B.

At the same time, panorama-capture technologies developed further. Several types of panoramic cameras were created, based on the way they capture images. These include:

- *Rotary cameras*: this is essentially a motorised rotary camera technology, which is usually equipped with a lens of normal focal length. This technology is still used today in various modifications by various manufacturers of photographic equipment.
- *Rotating lenses*: uses the technology of rotating the lens at the so-called no-parallax point against the film. This technology is used, for example, by the "Horizont" camera, which shot on 35x58 mm film. Today, its upgraded version, the "Horizont 205PC", takes pictures on roll film with a frame size of 55x110 mm.
- *Wide-angle cameras*: lenses with a very wide angle of view are used here; some of these types are still used today. With the further development of photographic technology, this type of photography gradually became increasingly effective in depicting space. The advent of digital technologies enabled spherical panoramic photography to work with these images much more easily using a computer and on monitor screens. From the point of view of modern digital cameras, taking a photo is now a matter of a moment, and its subsequent processing is more or less a matter of the software used.

3. Panoramic projection

It is a method of projecting three-dimensional space onto a monitor's display surface or onto paper. These are techniques used by cartographic workplaces in practice for processing and working with maps. It involves transferring

the representation of the space of a sphere onto flat paper in such a way that there is as little distortion as possible. There are many types of individual cartographic projections, but only a few are suitable for practical use in spherical panoramic photography. This is mainly the family of cylindrical projections, which belong to the classic type of display; then there are azimuthal projections; and finally, there are other types of projections that cannot be classified from a photographic point of view simply into the previous groups.

3.1. Cylindrical Projection

These projections include those that resemble a classic rectangular map of the world. The field of view is up to 360° horizontally and the vertical distance is relative according to the angle above and below the horizon. Cylindrical projection in photography is one of the classic ways to convert space into a planar image. Here, the image is not projected onto a plane, but onto the surface of a cylinder, which is then “unfolded” into a plane. The result has its own specifics, which are quite noticeable in practice.

- **Cylindrical Projection:** It is probably the most common type of panoramic projection. The full $360^\circ \times 180^\circ$ range of the space can also be displayed in this way, but in the area of the poles the image is already very distorted. This type is used mainly for prints of panoramas with a large range in the horizontal plane. (see Fig. 2)



Fig. 2. Cylindrical projection of a park with trees of $360^\circ \times 180^\circ$

- **Mercator Projection:** This is a conformal projection that has less distortion than the classic cylindrical one.
- **Equidistant Cylindrical Projection (Equirectangular):** It is a type of projection that represents a sphere in which the meridians are spaced the same distance apart as the parallels. (see Fig. 3) This type of projection is often used as a source for panoramic viewers. It is also used to display global map systems such as Celestia and NASAWorldWind.

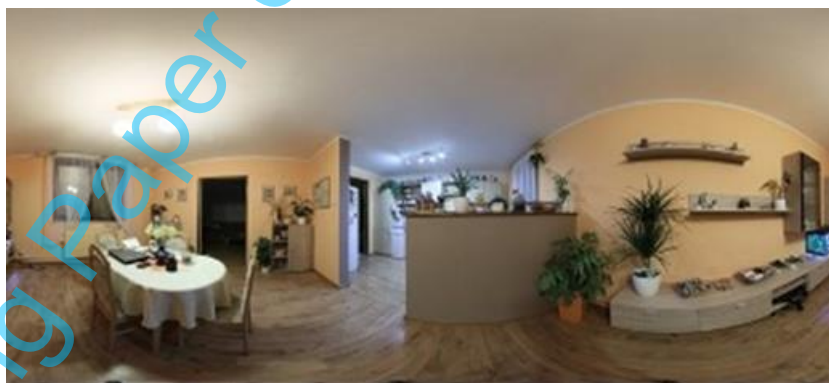


Fig. 3. Equirectangular projection of a room with a range of $360^\circ \times 180^\circ$

3.2. Azimuthal Projection

These projections exhibit axial symmetry about the center of the image. The image axis of these projections is a plane. These are the types of images that are produced by photographic lenses.

- **Rectilinear Projection (Straight Line):** It is probably the most common type of azimuthal panoramic projection. This projection preserves straight lines in the scene and in the resulting image. Therefore, the edges of the images are

stretched, resulting in significant distortion at the edges. (see Fig. 4) There is also often visible vignetting of the image. This type of distortion is mainly observed in images taken with wide-angle lenses.



Fig. 4. Image made with rectilinear projection

- **Fisheye Projection:** This projection displays a 180° hemisphere as a circular image. It is used with special “fisheye” type lenses. The image, of course, is distorted at the edges. Straight lines that extend off-center bend, the horizon curves into an arc, and the edges are strongly stretched. In a circular fisheye, the entire image is a circle and the rest is black (typically lenses with an 8mm focal length) (see Fig. 5)



Fig. 5. Fisheye projection

- **Stereographic Projection:** It is a type of projection in which the centre of projection is at the opposite pole to the pole touched by the imaging plane. It is a conformal form of the “fisheye” projection preserves angles between curves.

3.3. Other Types of Projections

This group includes other types of spatial representations that do not belong into the previous types of projections.

- **Cubic Projection:** This is a rectilinear projection representation but converted to the surface of a cube. (see Fig. 6) This type of representation is used for full-spherical representation, particularly in VR and game engine applications.



Fig. 6. Spherical image of the park, converted to cubic projection.

- *Sinusoidal Projection*: It is based on the Marin projection but has a large distortion in the polar region. In the area of spherical panoramic photography, it is supported by the older DevalVR software. In practice, it is practically not used for site documentation.
- *Little planet*: It is one of the types of stereographic projection that is interesting in its output. It is used more in creative photography (see Fig. 7)

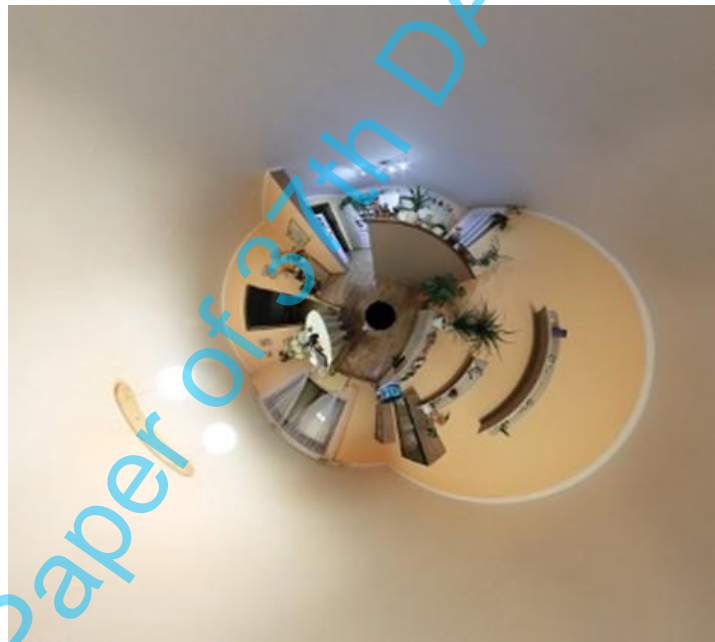


Fig. 7. Spherical image in the form of a "Little planet"

4. Taking spherical panoramic photos and dividing panoramic heads

To take a fully spherical image of space, it is, of course, necessary to use a tripod with a spirit level, which allows the camera plane to be set to a horizontal plane, and a special panoramic head. This allows the camera to be rotated around the so-called nodal point of the lens, which is necessary for later work with individual images. If the nodal point setting is inaccurate, it will not be possible to connect the individual images exactly to each other due to the parallax shift. Depending on the technique used, the number of individual images needed to create a complete panorama will vary. As a rule, for a camera with a 36x 24 mm chip format and a lens according to the focal length, this is 2, 4, 6 images, in the case of using a "fisheye" lens, or, for example, 47 images in the case of a focal length of 17 mm.

Panoramic heads can be commonly divided into three main types: fully automatic robotic devices, motorised, and manual heads. Of course, other technologies have been added recently, including integrated 360° cameras (so-called

multi-lens systems) the ability to compose panoramas using mobile phones and drones. This will also include industrial panoramic and VR systems, which typically operate as multi-camera rigs or combinations of a camera and LIDAR. The most important representatives of these categories are listed below.

- **Robotic, fully automatic devices:** This category includes the most expensive devices that not only capture panoramic images but also process them further to the final output, which can also be in the form of a virtual tour. This includes, for example, the Spheron VR 6 device [5]. This device, which is also used by the Police of the Czech Republic (Institute of Criminalistic Prague, OKTE Brno), includes its own SceneCam ® device for capturing a spherical image in fully automatic mode and SceneCenter® software for subsequent image processing.
- **Motorised heads:** One important representative in this category is, for example, the GigaPan EPIC Pro for DSLR Cameras head [6]. This is a fully automated head that can take several hundred pictures automatically. To take panoramic shots, all you need to do is set the edges of the resulting shot using the LCD display; the head software will handle the necessary calculation for the number of shots and rotate the head as many times as needed. The supplied GigaPan Stitch software, of course, allows user to compose the resulting spherical image and publish it on the GigaPan.com website, where results can be viewed and shared. The head design allows a 360° horizontal shooting range and -65° to +90° vertical shooting range.
- **Manual heads:** This category includes heads that require manual rotation. A typical representative is the Novoflex VRsystem PRO II HD head [7]. This is a very robust product from a well-known manufacturer; the head is equipped with a manual rotator that lets you easily set the required number of frames. The design of this head allows a 360° horizontal shooting range and -90° to +90° vertical shooting range. It allows the use of lenses with different focal lengths in combination with different camera bodies.
- **Specialised devices for 360 photography:** These include cameras that use two or more extremely wide-angle lenses. After taking a picture, real-time processing results in an immediate 360° output. Compared to the classic method of taking spherical images, the current disadvantage of this technology is lower detail, seams may be visible in the case of very close objects, and, depending on the technology, some types have a limited dynamic range. Typical devices of this type include Insta 360 or GoPro MAX2.
- **Mobile phones:** This is currently the simplest method of taking panoramic images. The principle is to smoothly rotate the mobile phone while simultaneously capturing the image. Modern mobile phones currently have sufficient computing power for virtually instantaneous image stitching and subsequent visualisation. Like other methods, this one using a mobile phone, has certain limitations and shortcomings. The biggest ones include limited resolution and artifacts in the image during rapid capture.

5. Software for composing images and virtual tours and presenting them

For further processing of the captured images, it is necessary to use software that allows the individual images to be "stitched" into the resulting spherical panoramic image.

If we are going to process individual panoramic images into the resulting virtual tour, we also need software that can connect images using hotspots or insert other files. These can be photos, videos, or sounds that are part of the virtual tour. As for programs for "stitching" images into a spherical panorama, we have a choice between commercial or free programs. Only commercial programs are available for creating a virtual tour. The presentation of the finished virtual tour or spherical image can be done in several ways. It depends on the software used and the requirements of the client. In general, the final output can be exported as HTML, which can be displayed on practically most browsers that support HTML5 technology. The finished product can also be exported as a separate *.exe file. As for describing the differences between the individual programs used for composing panoramas, it would be too extensive, so only a few representatives are listed here.

1. *Hugin 9* [8]: is an excellent program for composing panoramas. Its advantages include multiplatform support, good user control, a large number of settings for composing and blending images. Its other advantage is availability: it is available as a free application. Working with this program is relatively simple and intuitive, and, in addition to automatically glueing individual images, it also allows manual correction of junction points. It can also compose flat panoramas, multirow panoramas and correct lens distortion, for example, in architectural photographs.
2. *PanoramaStudio 4 Pro* [9]: is a cheaper commercial program that, however, offers very high utility value. The program can not only compose cylindrical or spherical panoramas but also connect individual images using hotspots. It works with many image formats, including *.RAW. It also contains a very extensive database of cameras, with which it works without any problems. It allows not only automatic stitching of images, but also, like Hugin, manual editing of contact points and working with them. The output from this program can be in the form of a spherical image in *.html format or in the same format as a 2D zoom photo. It also allows inserting a logo, adding music, setting automatic playback parameters, or displaying control elements.
3. *Krpano* [10]: is a high-performance panorama viewer and framework that allows you to display panoramic images and virtual tours on the web. Its undeniable advantages include high flexibility and user-friendly settings. Of course,

it can't do everything; its main disadvantages include the fact that it can't compose users' own panoramas (it is necessary to use another program), and its operation is not entirely intuitive.

4. *Easypano Studio* [11]: is one of the best products in the field of panoramic photography and virtual tours. It is also a multiplatform product, for both Windows and MacOS. It is a package that contains multiple products, depending on the version. It includes Panoweaver 10, a software for composing panoramic images. It can not only compose a panorama, but it is also able to publish it in multiple formats such as Flash *.swf, HTML5 and Java Applet. It can export its own spherical photos as equirectangular or cubic panoramas and convert between formats. It uses both classic photos in *.JPG format and *.RAW format as its input format. It can also work with 16-bit images and can compose HDR panoramas. The second program in this package is Tourweaver7. It is used for composing virtual tours. The program allows, for example, the insertion of finished panoramas, individual images in several formats, and independent pop-up windows and maps. The output can be done either classically in a precisely defined window or fullscreen. It can render individual hotspots and display the corresponding angle of view from the selected hotspot on a circular sector. Of course, there is the possibility of connecting individual panoramas to each other, both using hotspots and using maps or plans. There is also the possibility of direct links to panoramas from the own menu. The SWF, *.exe format can be used as output. Its great advantages include user variability.
5. *3DVista Virtual Tour* [12]: is again a package of programs that allows you to compose your own panoramas and distribute them as virtual tours. The advantages of this software include user-friendliness, the support for many image formats, and, of course, support for various output formats.

6. Virtual tours and their use in practice

A virtual tour is a modern interactive representation of space. It is a relatively young process, as it is essentially tied to the use of a PC, and its first practical use dates to 1994, when a virtual tour was conducted at the British Museum following the reconstruction of Dudley Castle, which has stood in England since 1550 [13]. For example, unlike video recording, it allows the user to react immediately to a given location. With a virtual tour, it is relatively easy to show the area at the crime scene in relation to its surroundings using plans or embedded maps. Another key advantage is that no special program is needed; standard PC software and web browsers (IE, Google Chrome, Firefox) suffice. Unlike simulated 3D visualization, it displays real rooms or exteriors. The 360° horizontal and 180° vertical viewing angles of spherical photos give a much better idea of the presented space than a regular photograph. Screen shows virtual tour of presented location giving more immersive feeling for the user. View can be controlled using the keyboard or mouse allowing to change the angle to a specific spot and even zooming in on the objects of interest. The actual work of creating virtual tours generally consists of two phases. In the first phase, individual photos are taken on site, depending on the location that needs to be documented. Depending on the technique used, the time required to work at one location is between 5 and 15 minutes (including balancing the tripod and taking photos). The second phase consists of subsequently transferring the photos to a PC and processing them. The time required here varies, depending on the hardware (performance) of the PC, the number of individual photos that make up the panorama, the total number of locations where the panoramas were taken, and the requirements for the overall implementation of the virtual tour.

7. Digital data integrity and evidential value

If spherical panoramic images and virtual tours are to be used in criminal proceedings, the processing workflow must not compromise the integrity of the digital record. Consequently, the processes of stitching images, blending them, and inserting interactive elements should be viewed as the creation of new, derivative files rather than as alterations to the original data. This means that work must never be performed on the original images themselves, but only on copies.

The primary record consists of the original images captured at the crime scene, ideally in RAW format. Their EXIF metadata (capture date and time, camera model and serial number, lens details, and other parameters) documents the circumstances under which the images were taken. Stitching software loads these files and generates a new image in a chosen projection—typically equirectangular or cubic. This process involves geometric transformation and resampling of the image data. Subsequent operations—such as blending, exposure balancing, or vignetting correction—alter individual pixel values, particularly in the overlap areas between adjacent images. Depending on the software used, EXIF data may be retained from only one of the source images, partially lost, or supplemented with new information (e.g., the name of the processing software or specific XMP tags for panoramas). Interactive elements, links between panoramas, and embedded multimedia content are typically stored in separate configuration files (e.g., XML or JSON); furthermore, the panorama itself is often split by the viewer into smaller tiles, within which the original metadata is generally not preserved at all. Thus, a virtual tour constitutes an interpretive presentation layer built upon the primary data, rather than the primary record itself.

The auditability of this process is ensured through a combination of cryptographic hashing and workflow documentation. Immediately after capture, the original files should be copied from the memory card and stored on independent media, and a hash value should be calculated for each file using a current algorithm, such as SHA-256 [14]. MD5 and SHA-1 algorithms are no longer considered collision-resistant. The calculated hash values are recorded in the documentation and verified at every stage of transfer or archiving. Any change to even a single bit of the file—including metadata modifications—results in a different value, making it possible to demonstrably track any alteration to the file.

All further processing is performed exclusively on working copies. For derived outputs (such as a stitched panorama or an exported virtual tour package), the hash value can only prove that the output has not been altered since its creation; it cannot, however, prove identity with the original data. For this reason, software settings, version details, processing parameters, and project files should also be archived so that an independent expert can trace the process and recreate the output from the original data. This approach aligns with the general principles for handling digital evidence outlined in the ISO/IEC 27037 standard [15]—specifically the principles of integrity, traceability, and repeatability.

However, it must be emphasized that a hash value confirms the integrity of a file, not the veracity of its content. In criminal proceedings, the virtual tour should remain a supplementary visual aid to the scene examination report and the original photographic documentation, the latter of which continues to constitute the primary evidence.

8. Conclusion

This article was not intended to analyse or describe in detail the individual procedures, methods and programs used for working with spherical panoramic photography and virtual tours. This is rather a brief outline of what this technology enables, its history, current state, and processing options. Virtual tours are increasingly used in the practice of security forces, especially in documentation, training, and analysis of events (see Fig. 8). One of the important areas of use is forensic documentation of the scene of an incident. Panoramic images capture the spatial arrangement of the crime scene in its entirety and thus provide a comprehensive visual overview of the entire situation at the time of the inspection. Such documentation can be used in the reconstruction of events, in expert work or in the presentation of evidence during criminal proceedings. Virtual tours are among several options for processing documentation of CSI and other forensically relevant events. They are a very good option for a person who was not directly on site to orientate themselves on the scene. Another important area of application of virtual inspections is the training and preparation of security forces. The virtual environment allows for the realistic simulation of various types of objects and situations, such as buildings, vehicles, and public spaces. Police officers, firefighters, or other workers can use virtual inspections to analyse the layout of objects, plan tactical procedures, or practice interventions in an environment that corresponds to real conditions. Virtual inspections can also be used when planning interventions at high-risky sites, such as industrial sites, schools, or transport hubs.

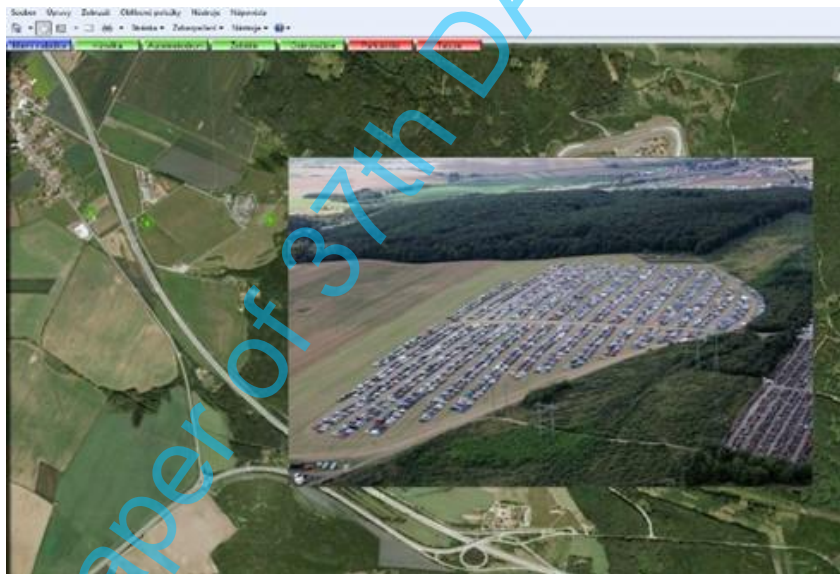


Fig. 8. Sample output of using a virtual tour at the Moto GP in Brno

Another possibility for using panoramic photographs and virtual tours is the implementation of a security assessment of objects as part of the design process for alarm systems (alarm security systems, camera systems, access control systems), security measures (regime measures, physical security), and mechanical barrier systems. Although a virtual tour does not replace an actual inspection report, photo documentation, or video documentation, it serves as an effective illustrative tool and is relatively straightforward to acquire. Overall, it can be stated that virtual tours represent a significant tool for modern digital documentation and spatial visualization. Within the security sector, they can contribute to better documentation of events, more effective training, and better preparation for dealing with emergency situations.

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