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# Direct use of point clouds in real-time interaction with the cultural heritage in pandemic and post-pandemic tourism on the case of Kłodzko Fortress

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ABSTRACT

In the aftermath of the COVID-19 pandemic, technology and interactive communication methods increased in importance. One of the sectors most affected by the lockdown was the tourism industry. It became necessary to apply a new approach to the research and development of this field using the virtual world. This paper presents the implementation of direct use of raw point cloud data enriched with digital historical resources on the case of the historic Klodzko Fortress in Poland's Lower Silesia. Terrestrial laser scanning was used to visualise the real world, later used in a game engine to create space for real-time virtual interaction. Like the touring paths in the real world, the interaction in the adopted solution went beyond observation and understanding of the space unified with historical resources. The project's overall goal was to create a safe and accessible digital tool to popularise the region's cultural heritage resources in pandemic and post-pandemic times.

## 1. Introduction

The COVID-19 pandemic has affected human life in every aspect, particularly severely undermining the socio-economical foundations of Europe and the world. That situation has been reflected in global tourism, which recorded historically low levels with an estimated 73% decline in 2020 compared to previous years (UNWTO, 2021). Individual countries took measures to contain the pandemic, such as closing borders, initially partially and then entirely, suspending domestic and international flights and closing access to public spaces (Osler, 2020). The lockdown had the fundamental effect of reducing and actually stopping passenger traffic and, therefore, the tourism industry. According to conducted studies, in 2021, about 32% of the world's tourist destinations are still closed, converting into drops in the tourism sector. Compared to 2019, in February 2021, the number of international tourists fell by 85%, representing around 260 million people. The *World Tourism Organisation* has created two future scenarios based on current trends and factors, such as a structured vaccination programme, increased air transport and safe travel procedures (such as the Digital Green Certificate - subject to a negative coronavirus test). The first assumes the possibility of a recovery in global tourism in the second half of 2021, increasing to 66% in July compared to the 2020 minima. The second assumes a 22% increase in September compared to 2020. Despite the above estimates, the second scenario would result in 67% fewer arrivals than in 2019 (UNWTO, 2021).

Following the worldwide spread of the COVID-19 virus, many measures were implemented to limit the pandemic. One of the sectors most affected by the restrictions was the cultural sector. According to UNESCO, 2020 report on the functioning of the world's museums in the face of a global pandemic, around 90% of all facilities covering nearly 85,000 cultural institutions have closed, and around 10% of them are unlikely ever to come back into functioning. Most of these are privately owned museums that need funding, which had been raised from ticket and admission sales, thus making operation dependent on visitor numbers. There is also a noticeable difference in the facilities' digital accessibility. Only 5% of African and island nation (SIDS) museums provided internet access to visitors.

In 2020, it was estimated that the number of museums worldwide is around 95,000, which is about 60% more than in 2012 (UNESCO, 2020). It is important to remark that the museum sector has rapidly taken measures to maintain contact with visitors, thus adapting to UNESCO's 2015 recommendations (UNESCO, 2015). Through the implementation

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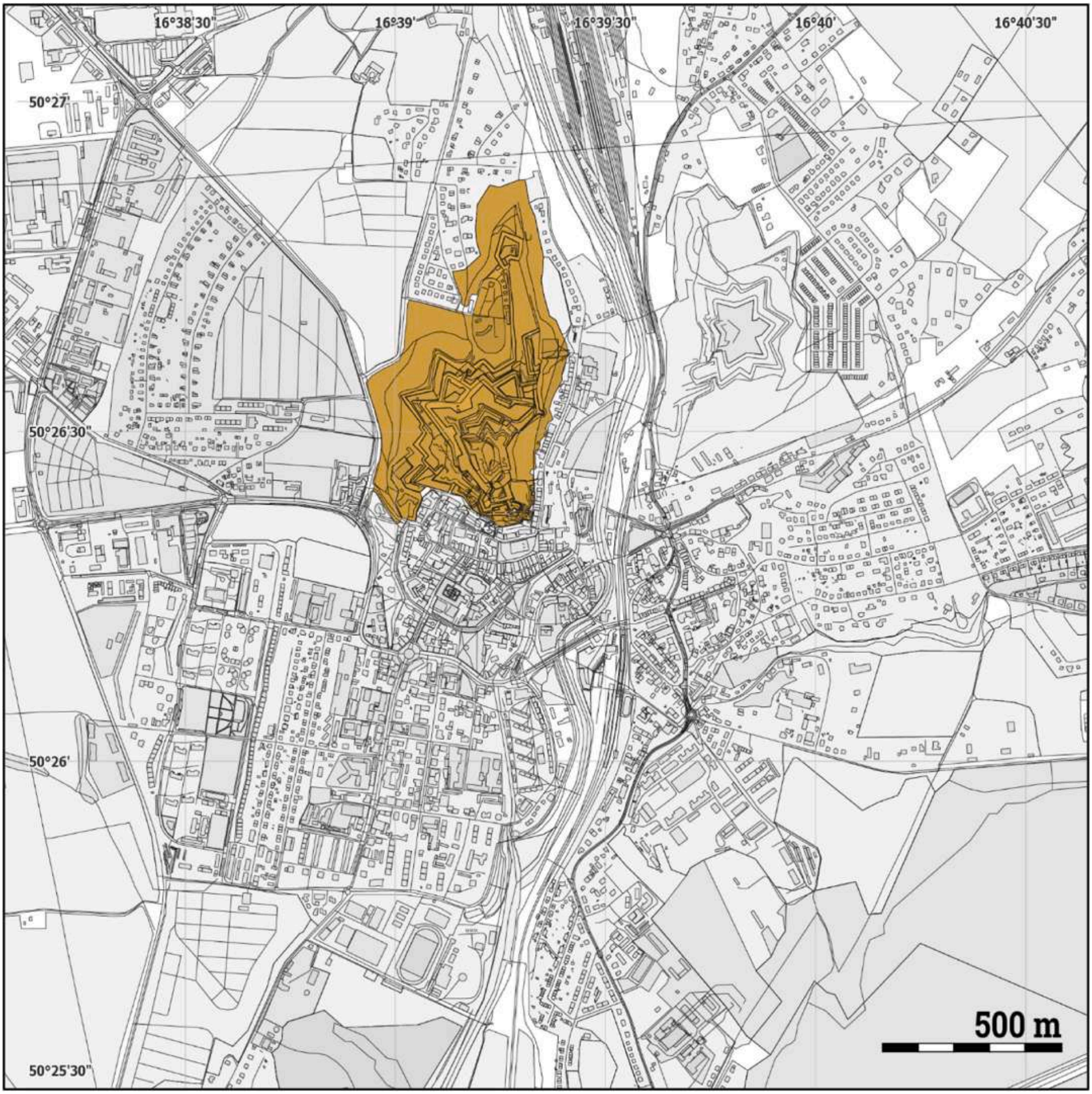


**Fig. 1.** The location of the fortress and its relation to the town of Klodzko – own elaboration based on www.openstreetmap.org.

of fundamental functions such as heritage preservation, research, public education, and above all communication, including disseminating knowledge about collections, sites, and monuments in the form of permanent exhibitions and digital resources (UNESCO, 2015). This last activity had become crucial in the pandemic when cultural life was moved to the Internet (UNESCO, 2020). Among the activities to make museum collections available online, social networks such as Facebook, Instagram, Twitter were used for promotion purposes. One might notice that while virtual museums and social media campaigns have emerged on all continents, ICT innovation activities have been observed in countries and museums that have previously invested in digital technologies. The digital gap between societies is now very apparent, as evidenced by the International Telecommunications Union data. Almost half of the world population does not have access to the Internet (UNESCO, 2020). However, this does not change that the only reasonable solution is to make collections accessible through tourism shaped in virtual reality in the current situation. Its essential conceptual elements are "presence" and "telepresence" (Arunasalam and Good, 2013), i.e. "computer-mediated sensory experiences that facilitate access to the visual and auditory dimensions of the destination" (Pizam, 2009).

This article attempts to answer how virtual real-time interaction can be used during and after a pandemic and what tools should be used to optimise the performance of the virtually assisted tourism sector. The paper presents a proposal for the creation of a virtual environment based on a point cloud. The presented solution is an attempt to build a tool integrating multiple heritage sources and information. The main

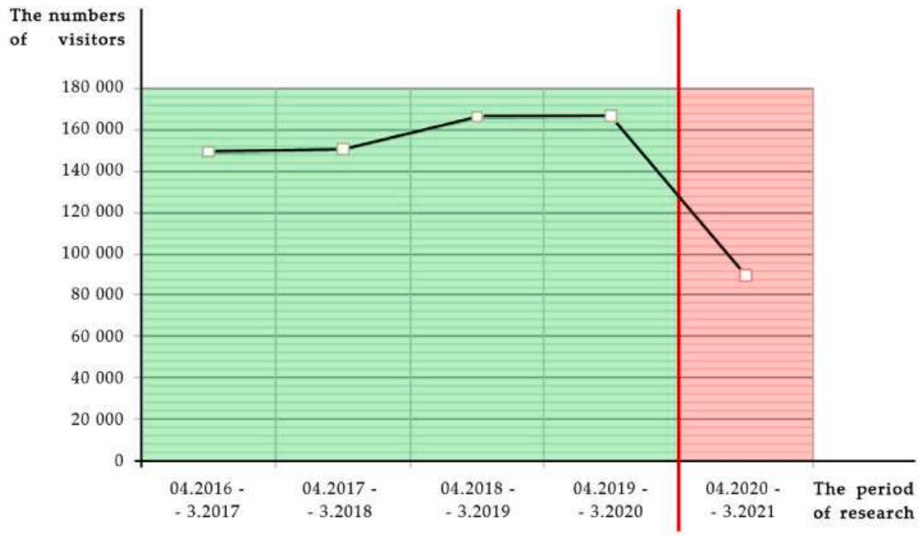


**Fig. 2.** Graph showing the number of visitors to the Kłodzko Fortress before the SARS COV 19 pandemic (green) and after the year of the pandemic duration (red) - the authors' elaboration. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 1**
Technical specification of the 3D scanner Leica ScanStation C10 Source: www.leica-geosystems.com [access August 24, 2021].

| TECHNICAL SPECIFICATIONS | |
|---|---|
| Accuracy of the single measurement | |
| Situation* | 6 mm |
| Distance* | 4 mm |
| Angle (horizontal/ vertical) | 60/60 microradians (12"/12″) |
| **Accuracy of modelled surface** | 2 mm |
| **Shields scanning** | Standard deviation – 2 mm |
| **Laser scanner** | |
| **Type** | Pulse, own layout |
| **Colour** | Green, wavelength 532 nm |
| **Laser class** | 3R (IEC 60825-1) |
| **Range** | 300 m by 90% of albedo; 134 m by 18% of albedo, (minimum range 0.1 m) |
| **Speed of scanning** | Up to 50,000 pt/s, maximum speed, temporary |
| **Scanning resolution** | |
| Size of the laser dot | From 0 to 50 m: 4.5 mm (FWHH test); 7 mm (Gauss' test) |
| Distance between the points | Selected horizontal and vertical, minimum distance, 1 mm, in all range, single points |
| **Field of vision** | |
| Horizontally | 360° (maximum) |
| Vertically | 270° (minimum) |
| Aiming/orientation | Free from parallax, integrated camera with zoom |
| **Scanning optics** | Mirror turning vertically or scanner platform turning horizontally; Smart X-Mirror™mirror turns automatically, shortening scanning time |
| **Laser plummet** | Laser class: 2 (IEC 60825-1)<br>Accuracy of centring: 1.5 mm at the height of 1.5m<br>Diameter of laser dot: 2.5 mm at the height of 1.5m |

objective is to visualise and synthesise the heritage site and its environment using a clear graphical language.

## 2. Theory

Virtual reality technology in computer games is becoming an original way to learn the culture, art, and material heritage (Ghanbari et al., 2015; Parrinello and Dell'Amico, 2019; Szewerniak, 2016). Nowadays, the computer technology of the virtual world has become an indispensable element of our everyday life (Webb, 2008), to which the COVID-19 pandemic has significantly contributed. The consequence of this process is the shift in various fields of the economy to the virtual world, and one of them is the aforementioned virtual tourism (UNESCO, 2020). This activity enhances the safety and convenience of use by integrating digital content with authentic images in the cognitive process of the cultural heritage resource (Vecchio et al., 2015). Through the transformation of actual history into remembered history, adaptation to the needs of a modern tourist occurs (Assmann, 2015), and the availability of virtual reality, through mobile applications or digital systems, becomes the most popular means of communication and spreading knowledge about cultural heritage. Popularisation and development of the virtual world integration with tourism have been observed since 2010 (Egger and Bulencea, 2015; Maj, 2010; Sanders, 2014). One of the tools used in the development of cultural tourism is the so-called Gamification, the term defined in 2008, which aims to stimulate the motivation of a recipient (Vecchio et al., 2015). Currently, it is an opportunity and a future method for developing the tourism industry (Deterding et al., 2011; Elmi et al., 2018), providing an alternative to decreasing tourist traffic. It is predicted that this kind of technique will become more and more popular, and the tourist experience will become more remarkable (Xu et al., 2017).

Modern society relies mainly on sight during the cognitive process (Poczta and Mariianchuk, 2013). Virtual tourism offers us unlimited time, which can be devoted to sightseeing and getting to know the site, its elements, details, or history. Such cognition is not possible in traditional guided tours where we get much information in a short time. Therefore, it is not possible to absorb and analyse it thoroughly and thus remember and understand it. Hence a virtual tour can be a more immersive experience than a tour in the real world. It has several advantages, the most important of which, from the cognitive point of view, is the possibility to organise and systematise information. Thus, the above statement is in line with the current trend of Cultural Heritage as an evolving concept. It is a process that gains another cognitive dimension due to virtuality (Szewerniak, 2016).

Tourism through computer games allows broadening a viewer's perspective with a different perspective compared to physical sightseeing. It also engages many other senses and ways to explore spaces unavailable during traditional sightseeing (Xiang and Tussyadiah, 2013). It focuses not only on the entertainment function but also on the cognitive function (Ghanbari et al., 2015). In virtual space, a viewer has the possibility of moving in a "traditional" way. However, what is more, by using various filters or animations, they may be taken to a chosen period in history. Such techniques have been used, for example, in the

**Fig. 3.** Leica ScanStation C10 during measurement with a laser beam – the authors' photography.

Assassin's Creed game series, first released in 2007. It is an action-adventure game with an open world where the background of the action are struggles between two orders: the Templars and the Assassins (Nazaris). The game has also become famous for depicting well-researched historical conflicts and reconstructions of cities from past eras (Shaw, 2015). Many of the objects used and modelled were preceded by detailed architectural and historical research.

An example is the Assassin's Creed Unity game, set in Paris during the French Revolution and accurately represented Notre-Dame Cathedral. The player has the opportunity to move freely and explore the entire city not only by virtual walk but also by moving on the roofs of buildings or observing city panorama from other perspectives, e.g. from a "bird's eye view". It is worth emphasising that this type of perception is not available in physical sightseeing by a regular tourist (Szewerniak, 2016). However, it should be remembered that the aim of the game was not to reproduce individual structures accurately but to build the place's atmosphere and era, serving to build the story. The virtual worlds presented in subsequent series of the game cannot serve as an accurate reference because they are an interpretation created for the game's needs. In the game latest editions, photogrammetry and 3D mapping are applied to create as realistic as possible virtual spaces, indicating this technology's direction. Currently, the global gaming market is rapidly growing, significantly influenced by the COVID-19 pandemic outbreak. Due to this situation, it is estimated that mobile games will be the fastest-growing segment in the gaming market (Wallace, 2021).

An example of a Polish game used for entertainment and further development in historical, philosophical, sociological and ethical education is "This War of Mine" by "11 bit studios". The game uses a modern, natural and attractive to the viewer language of interaction, emphasising experiencing history. It is an example of technology implementation in the service of education. The uniqueness of that game is proven because it was incorporated into Poland's official school curriculum and is considered an educational tool. Similar activities to those used in games can be applied to convey and spread knowledge about architectural, cultural heritage, emphasising the integration of experiencing and exploring history.

## 3. Site description - general information about the surveyed facility

Nowadays, a monument cannot function in isolation from the economic situation (Szmygin et al., 2014). Post-fortress areas have particular aesthetic values and are a permanent feature in the landscape and panorama of their locations. The continuous progress of tourism is an opportunity for their future development and secure funding. Due to the global COVID-19 pandemic, there has been a significant decline globally and thus domestic tourism. The activities of the Kłodzko Fortress also reflected this, functioning mainly on financial income from visitors and guests visiting the facility.

The Kłodzko Fortress is one of the best-preserved ars militars in the Lower Silesian mountain range. The geographical location of Kłodzko (Fig. 1) and its political significance made the town an exceptional example of subsequent facilities of the fortification belt of the Sudeten Fortress. The preservation condition of this fortress as a whole makes it unique in the country (Stoklasek-Michalak, 2019). The fortification was located at the site of a medieval castle erected in the 14th century. The fortress's present shape and architectural form represent one of the most valuable military complexes developed in the 17th and 18th centuries. The entire complex consists of the Main Fortress with approximately 30 ha area, an auxiliary fort on Owcza Góra, and partially preserved ramparts of the town and field fortifications. The fortress ceased to serve a military function in the mid-19th century and started to be used as soldiers' barracks and a maximum-security prison. During World War II, SS quarters were functioning in the fortress area (Malchrowicz, 2011). After the war, the object was adapted to an armaments factory AEG, and then it became the property of the army stationed there (Kowal, 2015). In 1960, it was entered in the monuments' register (Decision KL-V-1/61/30 of the May 13, 1960 on entry in the monuments' register). Currently, the building is partially open for tourism and museum purposes. Following the Srebrna Góra Fortress example, in 2005, Kłodzko's city council passed a resolution on establishing the Kłodzko Fortress Cultural Park (Stoklasek-Michalak, 2019). Every year the fortress was visited by crowds of tourists. From 2016 onwards, an upward trend was noticeable, the lower limit around 150,000 people per year. According to the Kłodzko City Council data, in 2019, the fortress was visited by 167,168 tourists, with the most significant visitors' number in the summer months from May to August, when the tourists' number was estimated at around 30,000 people per month respectively. According to available research on the tourism potential of the Kłodzko Fortress, it is a significant tourism driver in the region (Kowal, 2015). According to research, the motivations of people interested in visiting ars militaris sites are as follows (Jędrysiak, and Mikos von Rohrscheidt, 2013): historical-educational (cognitive), martyrological, political-ideological, cultural-entertainment, recreational-sports, and

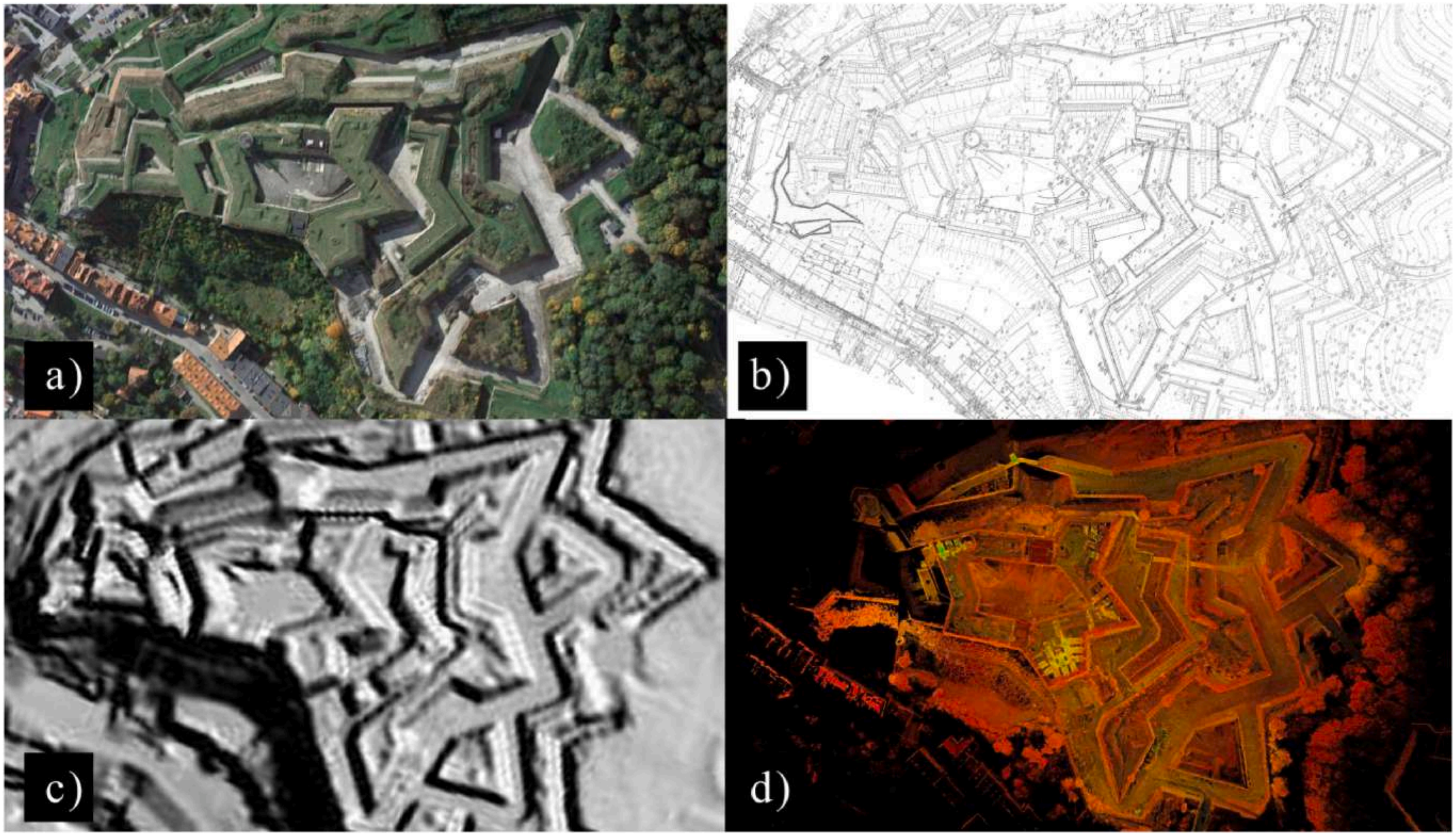


**Fig. 4.** Combination of satellite view a) with a geodetic map b) digital terrain model c) and point cloud d) – the authors' elaboration.

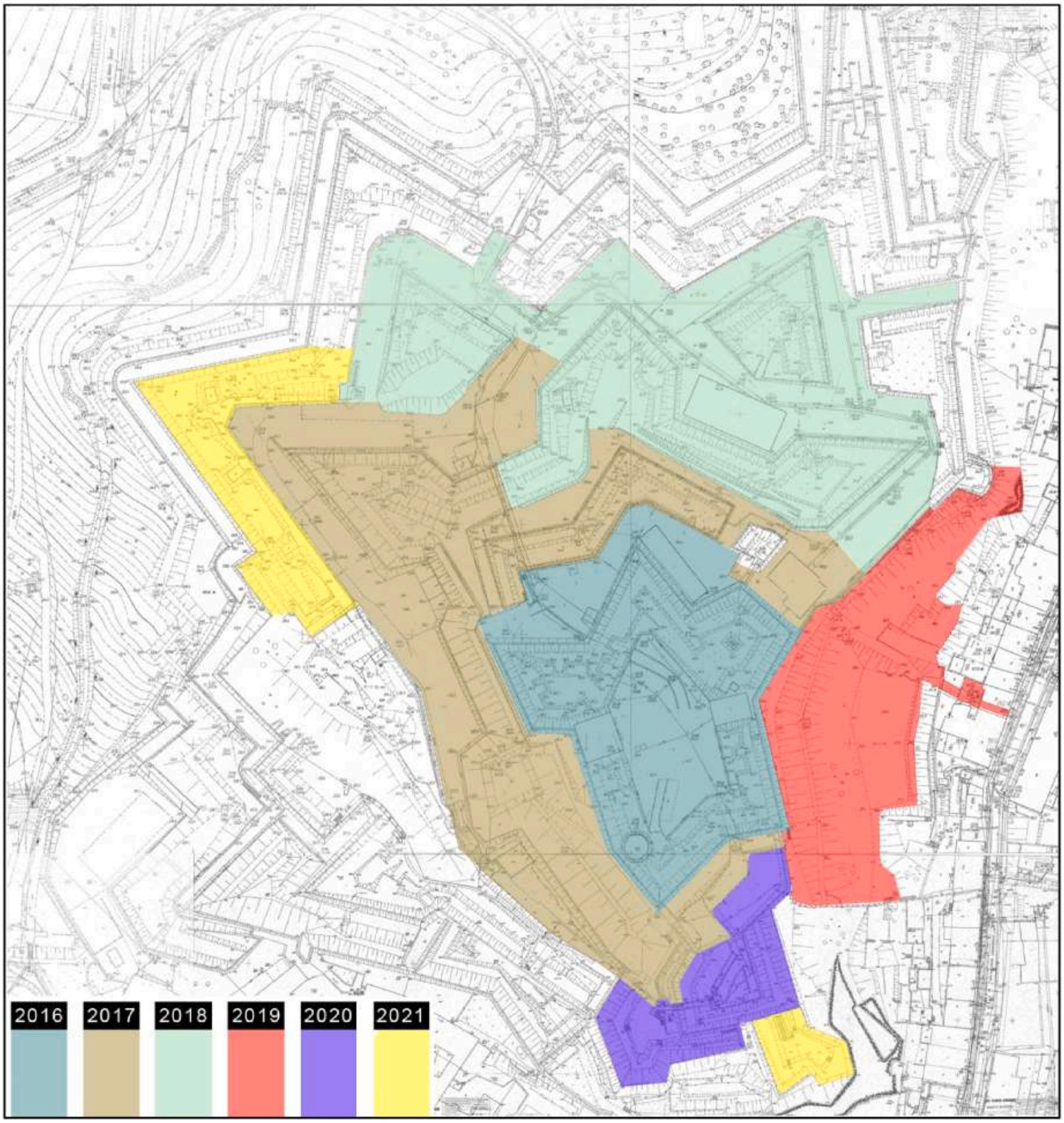


**Fig. 5.** Scanning stages by year – authors' elaboration.

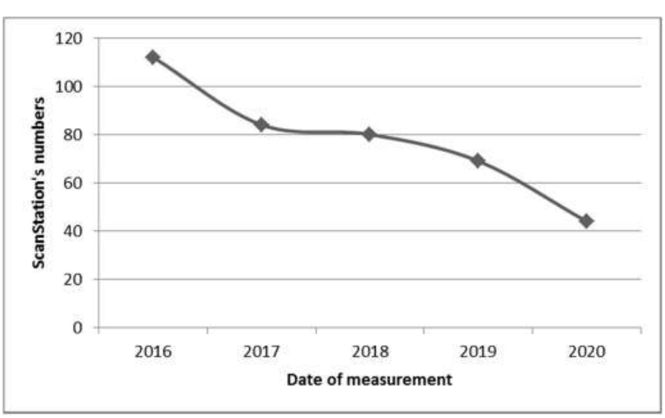


**Fig. 6.** Graph showing the change in the number of scans per 2016–2020 survey.

experiential.

As a result of the COVID-19 pandemic in 2020, the number of visitors dropped dramatically to around 58% of 2019 (Fig. 2). The tourism level in 2020 was dependent on the actions and restrictions imposed on the tourism sector due to the Government's decision to combat the pandemic and the subsequent lockdowns following the pandemic surge in the spring and autumn.

## 4. Terrestrial laser scanning (TLS) in Kłodzko Fortress

Before starting the project, a detailed archival and iconographic search of the Kłodzko Fortress was carried out. Its spatial structure and the transformations it underwent over the years were analysed. The study made use of materials from the resources of the Gehaime Staaysarchiv Preussischer Kulturbesitz, the Kriegsarchive in Vienna, the Digital Archive of the Polon National Library, the resources in the collection of the Adventure Academy Association promoting the scouting movement and operating in the fortress area, and several


**Fig. 7.** Alignment of the measuring device (a) and the target plate (b) during measurements - authors' elaboration.

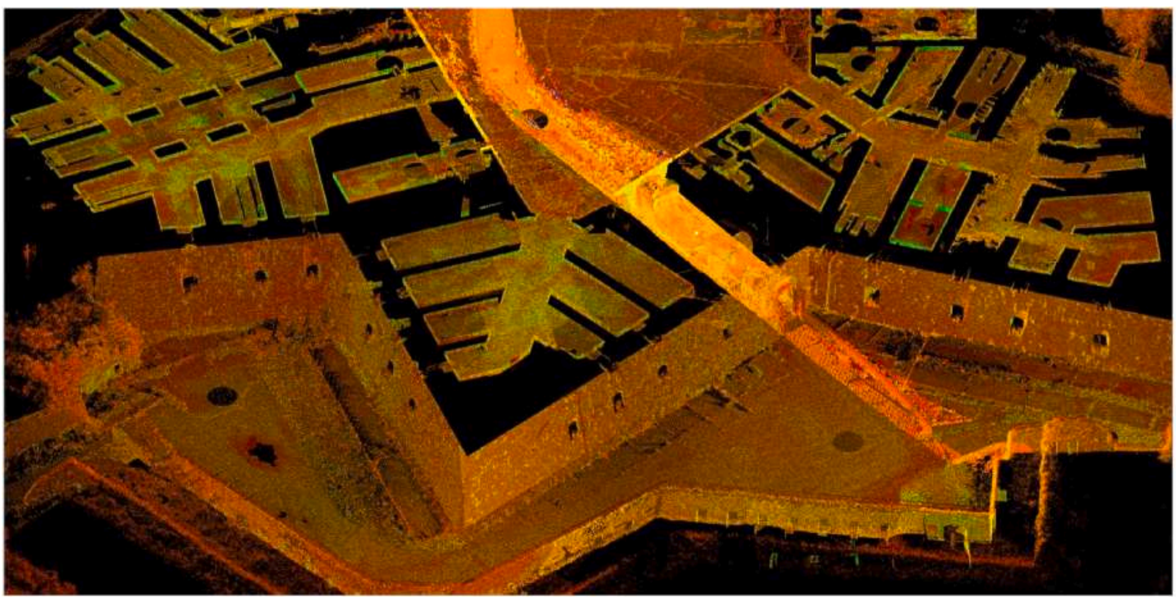

**Fig. 8.** Relationship between external and internal scans of an object – authors' elaboration.

regional studies from the collections of private individuals made available on Internet platforms. Those sources were the basis for the development of the original database collected in FileMaker Pro[1] software.

The performed survey of the Kłodzko Fortress lasting since 2016 consisted of scanning the fortress foundation, especially all internal fortress levels. During the surveying campaign, a ground-based laser scanner Leica C10 was used (Table 1). This scanner records information in point clouds through the emitted laser beam reflected from the scanned object (Fig. 3). The conducted research consisted of field measurements without photographs to speed up the measurements of such a large object. The point cloud created in this way provides the basis for subsequent work related to the survey, maintenance, and ongoing structure repairs (Gleń and Krupa, 2020). The TLS measurement technology used during the survey is currently one of the fastest and most accurate measurement methods (Gleń and Krupa, 2018). Laser scanning allows the acquisition of spatial data on existing buildings. The presented graphic (Fig. 4) illustrates the juxtaposition of a satellite view, a geodetic map, and a TLS measurement of the developed object. Terrestrial laser scanning is the total station technology expansion that implements mirrorless distance measurement. The speed and quality of data acquisition have increased (Becek et al., 2015). Using scanners in surveying work has many advantages, increasing their popularity worldwide (Rzonca, 2004). This technology acquires spatial data about the scanned object (its shape, texture, colour, dimensions, distance) using a laser beam sent from the measuring device (Remondino, 2011). As a result, of the survey, the source material was collected in the form of a point cloud of the whole Kłodzko Fortress fortification. The scanning covered the whole outer contour of the object and part of the interior.

The inventory process of the Kłodzko Fortress was carried out in stages from 2016 to 2021. The facility area covered by the scanning with the division into stages of annual measurements is shown in(Fig. 5). The complexity of the site's structure means that each of the stages consisting of 5-day scanning consists of a different number of sites. Open spaces require fewer positions, while indoor spaces (a network of corridors with different levels of complexity and accessibility) require the scanner to be positioned at much shorter distances, significantly increasing the measurement time. Another factor that makes scanning difficult is the measurement of wall crowns by moving the scanner over uneven terrain and invasive greenery, which increases the number of positions. During the measurements, discs were used to support the subsequent linking of the sites. In the first stages, the inner courtyards and moats were subjected to scanning measurements, while subsequent years consisted of measuring more complex elements such as earthen ramparts, casemates and places with difficult access (Fig. 6). By 2021,

[1] More about the software: https://www.claris.com/filemaker/.

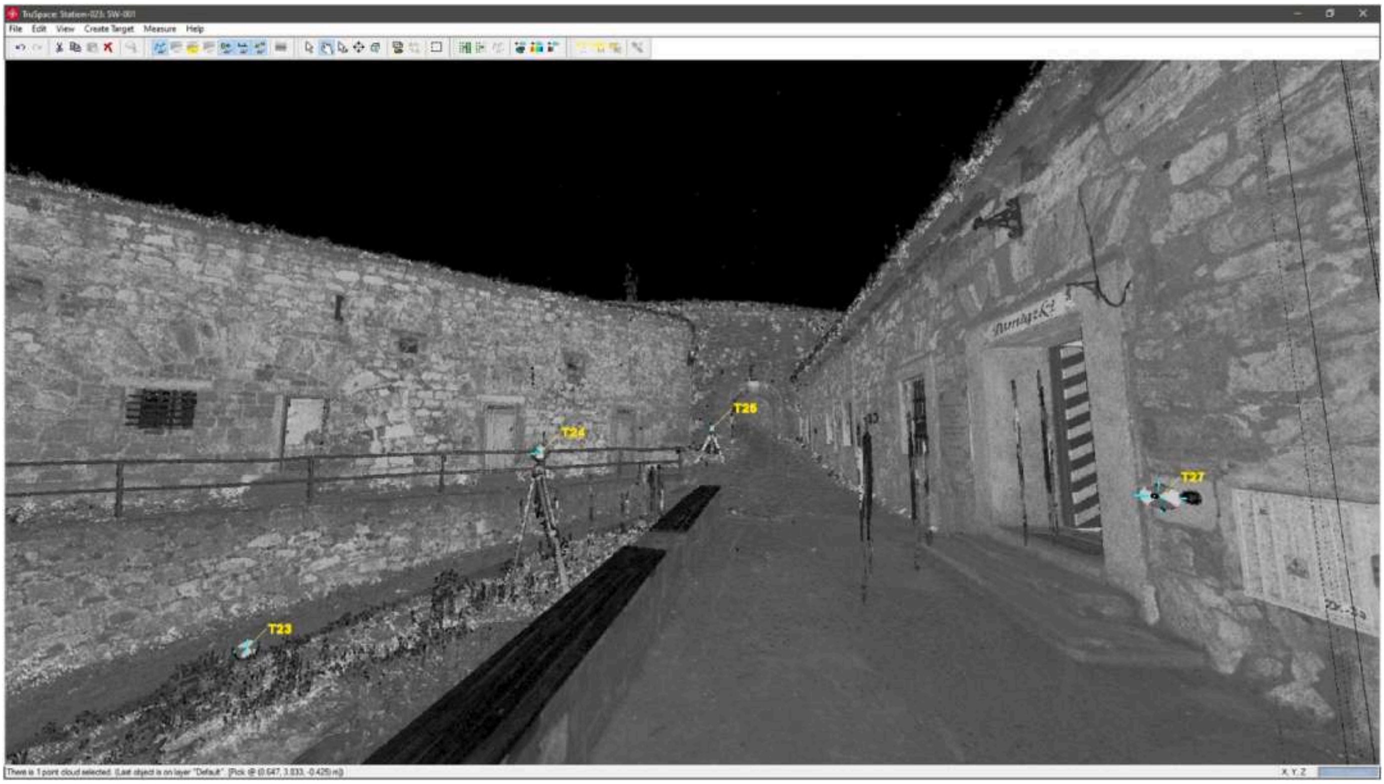


**Fig. 9.** Defined targets visible in Leica Cyclone 2020.1.0 scans – authors' elaboration.

**Fig. 10.** Point cloud representation of Kłodzko Fortress generated with Leica Cyclone software - the authors' elaboration.

about 80% of the entire fortress foundation and the parts under the earthen ramparts had been measured. The total number of measurement positions was 389.

Surveying the Kłodzko Fortress consisted of setting up successive scanning points (ScanStation) not far from each other so that each successive scan had parts in common with the previous one. This is an essential element of the scanning process and affects the later work of assembling the individual stations into a whole. Measurements were also made using support targets defined when setting up the scanner (Fig. 7). The targets were used to link the stations together afterwards automatically. During one scan, six targets were set up, of which three were treated as fixed elements needed during the following scan. Three were treated as movable elements. Each moving target was defined by a number (T1, T2, T3, …). During measuring, the density of positions increased in places where scans of external courtyards, earthen ramparts and scans of convoluted rooms merged. The correct positioning of the scanner resulted in the exclusion of folding errors giving a trustworthy relationship between the outer and inner scans (Fig. 8). This made it possible to estimate the individual building envelopes accurately and thus the actual relationships between the fortress elements needed for


**Fig. 11.** Drones used for photogrammetric survey of Klodzko Fortress in 2021. On the left a) DJI Mavic Air 2S and on the right b) DJI Mavic mini - photo by Michał Wac "Cyfryzacja Budownictwa".

**Fig. 12.** Photogrammetry 3D model of "Donjon" in Klodzko Fortress based on photos - study by Michał Wac "Cyfryzacja Budownictwa".

the subsequent representation of the fortress in the form of a three-dimensional model.

Once the field survey work was complete, the next step was to import all the sites into Leica Cyclone 2020.1.0 to merge them into one. In this process, both the scans and the position of the targets defined at the scanning stage are imported (Fig. 9), so combining scans was optimised using cloud-based object mapping.

The created database in the form of a point cloud (Fig. 10) serves to collect spatial data needed for the architectural survey, further work on the site, and make the digital model available for virtual tourism purposes.

The data gathered through TLS accurately represents reality and records the current state, expands our knowledge and understanding of a given space. It combines millions of coordinates in a three-dimensional virtual space, supplemented with location and colour data. Despite all the advantages and visual attractiveness, point clouds lack meaningful semantics. It becomes a problem to extract individual building elements, described as 3D Point Cloud Semantic Segmentation (PCSS) (Xie et al., 2020) and assign specific information like value, parameter or external data. Adding semantic information to individual elements requires some locations to which this information can be attached. The use of 3D solid objects simplifies the process of assigning information, as each object can be a separate file that forms part of the whole. Currently, no software allows a direct transition from a point cloud to a solid model created as an object enhanced with semantic data (Baik, 2020). This process requires careful analysis, determination of fragments, and unwanted elements verification. There is ongoing research (Croce et al., 2021) into automation and application of machine learning for shape and object recognition based on point clouds. The most common solution to this problem is working by hand (Iglesias et al., 2020). Those issues raise the problem of combining, processing, and managing information, including cultural heritage data. On the one hand, a large amount of data and very accurate spatial information is available, but on the other hand, not linked with other information. Enriching point cloud data with semantic information enables user interaction at the level of editing, use, display, and research (Galasso et al., 2021; Schnabel et al., 2007).

## 5. Use of photogrammetry data

The main problem concerning the developed issue of creating a virtual space on the basis of the performed measurements was the lack of available colour point clouds in the 3D model. This was due to the fact that the original aim of the 2016 to 2020 study was to gather as much

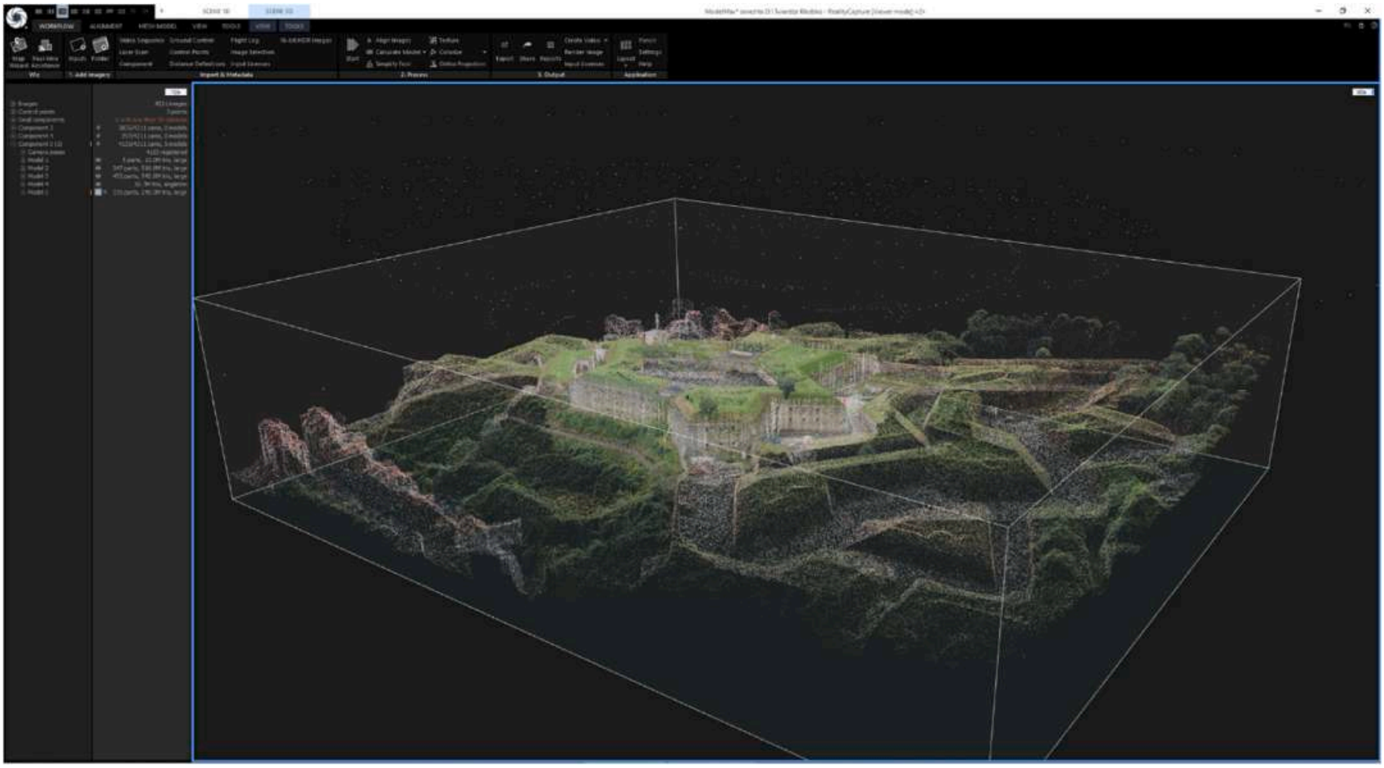

**Fig. 13.** Photogrammetry 3D model created in software Reality Capture - study by Michał Wac “Cyfryzacja Budownictwa".

range as possible in the relatively shortest time possible to measure the site database for the existing condition inventory. During the work with the 3D scanner, surveys were made without the use of photographs in the Leica C10 due to the significantly increased running time of the device (Nagrodzka-Godycka et al., 2015). The original aim of the task was therefore to obtain a scan showing the existing state of the Klodzko Fortess necessary to make an inventory documentation of the object. However, this does not change the fact that it is possible to supplement the model with photos taken on the basis of photogrammetric measurements by superimposing two images. However, it significantly prolongs the whole process. The survey stage at medium resolution (6 mm) without images from the Leica C 10 took about 7 min. The measurement with the photos extends twice as long and considering the changeable atmospheric conditions such as rainfall, the time reduction was vital. Working with a point cloud derived from photogrammetry is more time-consuming than a simple TLS measurement (Kraszewski and Brodowska, 2014). When using a drone equipped with a camera, the measurement accuracy is only focused on obtaining structure and color due to the numerous architectural and landscape barriers present on the site (Parrinello and Picchio, 2019). The use of TLS and photogrammetric in work on historic sites is crucial when defining 3D databases for cultural heritage conservation (Parrinello, 2020).

In 2021, research using photogrammetry was initiated at the Kłodzko Fortress in agreement with the company “Cyfryzacja Budownictwa”. Two drones DJI Mavic Air 2S (Fig. 11a) and DJI Mavic mini (Fig. 11b) with built-in F/1.1 lens were used to take perpendicular photographs of the site. Using the technology of 3D model creation on the basis of photogrammetric images, a preliminary model of the external walls of the ‘donjon’ was developed (Fig. 12). On this basis, a 3D model was created using Reality Capture software (Fig. 13). Working time on the measurements of the “donjon” of Kłodzko Fortress oscillated around 8 h of continuous work in which time 4200 pictures of the object were obtained. The time of processing the acquired data was 45 h of continuous work.

Considering that work on the photogrammetric model has started in 2021, work on its use in creating a virtual real-time interactive tour is planned as an extension of the discussed tool. This gives the possibility to provide a much more complex and valuable 3D model that is more accessible to the potential recipient. Creating a photorealistic virtual environment in an application dedicated to tourism could be achieved in the next stages of research related to the digitalization of the Kłodzko Fortress. In the next part of the article, the authors present a method of constructing a virtual model accessible to a tourist-based on the compiled data from the research area.

## 6. Virtual space for Heritage Interaction

The project’s overall goal was to create a safe and accessible digital tool to popularise the region’s cultural heritage resources in pandemic and post-pandemic times. The aim was to use collected point clouds and create a virtual real-time interactive tour. We created a script that connected historical database assets to parametric objects in assigned locations using XYZ coordinates and identification numbers. The presented method attempts to bypass the complicated 3D and object-oriented modelling process and directly use the raw point cloud data to convey knowledge about cultural heritage and present an interactive guide. Enrichment with digital historical resources emphasises the message, the visual experience and the role of active imagination (Alves, 2018) in virtual sightseeing.

### *6.1. Creation process*

The following solution simplifies the previously described issues related to TLS processing and recognition using human perception. In fact, through perception, we can quickly analyse shapes and qualify them as concrete objects, assigning them a basic scope of information (Biederman, 2013). This fact was used in the example to differentiate the point cloud density to highlight more and less valuable elements. The space scan served as an instrument for visualising the space and as a place for real-time interaction. Regarding sightseeing in the real world,

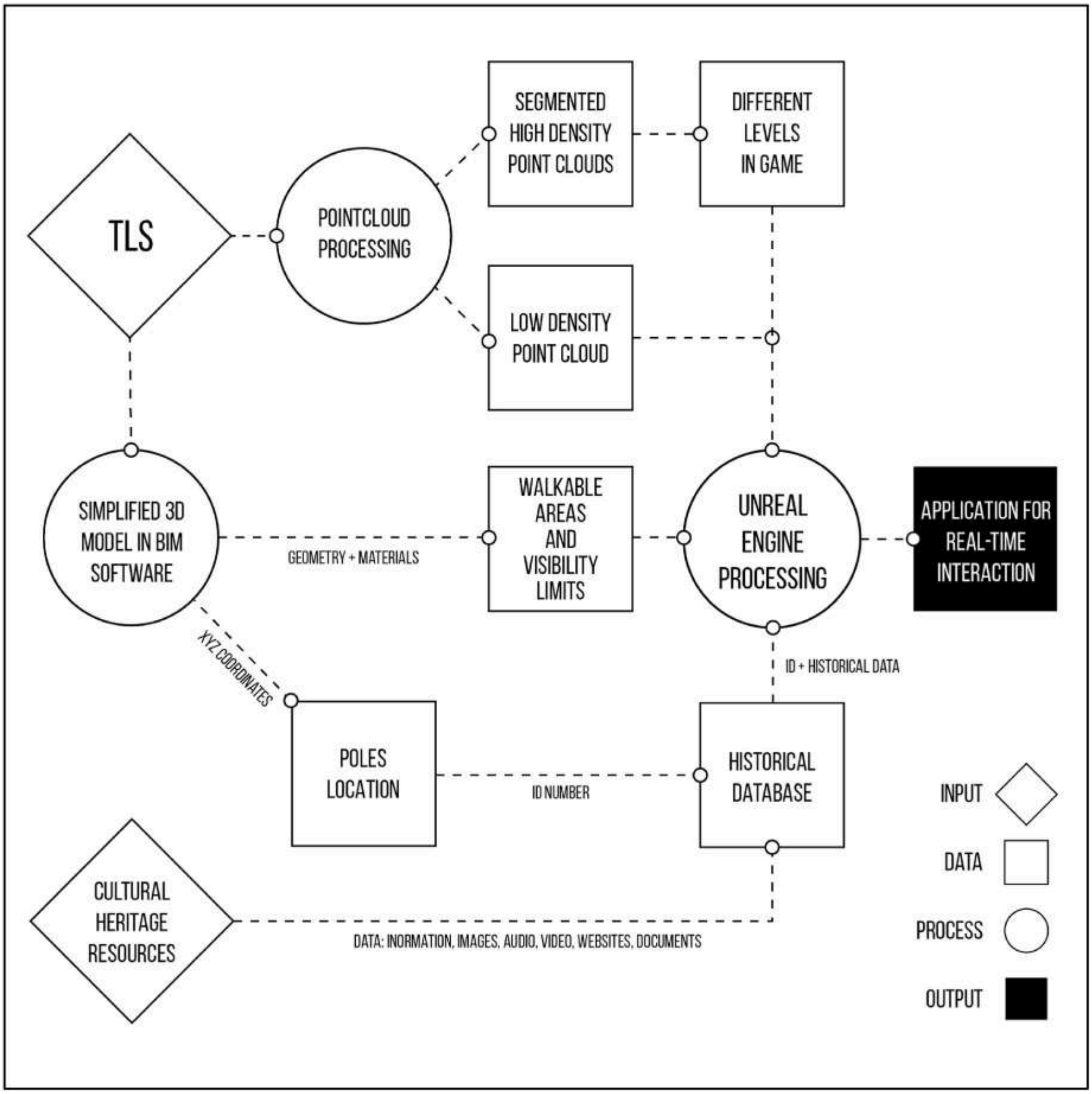


**Fig. 14.** Block flow diagram of the process – the authors' elaboration.

this interaction goes beyond observing and understanding the space by connecting to historical resources. Historical data comes in many forms, from oral transmission and textual recording to photographs, drawings and digital resources (Diara, 2020). Due to their quantity and diversity, this involves, among other things, the problem of their processing, management, standardisation, and accessibility. The project used database software (FileMaker Pro) to organise data and connect it through MySQL with the game development platform.

Working, editing, and visualising millions of points involves computing power and supporting hardware and algorithms problems. One of the more advanced tools to create real-time 3D assets is software used in game development - UNREAL ENGINE 4 (UE4).[2] The Virtual Space for Heritage Interaction (VSHI) was created based on UE4 and one of the most potent point cloud processors - the LiDAR POINT CLOUD (LPC)[3] plugin. The process (shown as the block scheme in Fig. 14) of creating the application starts with the point cloud acquired by TLS, as described earlier. The point cloud was exported from Lecia Cyclone in ". pts" format due to the LPC plugin supported formats (XYZ, TXT, PTS, LAS). To ensure performance and speed of display, we created a reduced density point cloud. It is always visible in virtual space, and the number of points is reduced to the minimum ("low-density point cloud" in Fig. 14) necessary to visualise and read the whole space. The random subsampling method removed 75% of points, and those left are displayed in a larger size to make them more visible. At the same time, to ensure the best possible representation of reality, the original cloud (exported from Leica Software) was split into smaller parts. In this way, segments are loaded into the application depending on the user's location. The process also involved cleansing the combined (after merging the individual scans) cloud of unnecessary elements (such as people, cars, animals, trash, distortions) to expose historical values of the site.

[2] Unreal Engine https://www.unrealengine.com/.The choice of the Unreal Engine platform was determined by the existing plugin - LiDAR POINT CLOUD and the ability to link resources to the FileMaker database. The applied method does not exclude the possibility of using other software, such as Unity (https://unity.com/), provided that cooperation and data exchange between platforms is ensured.

[3] LiDAR Point Cloud https://pointcloudplugin.com.

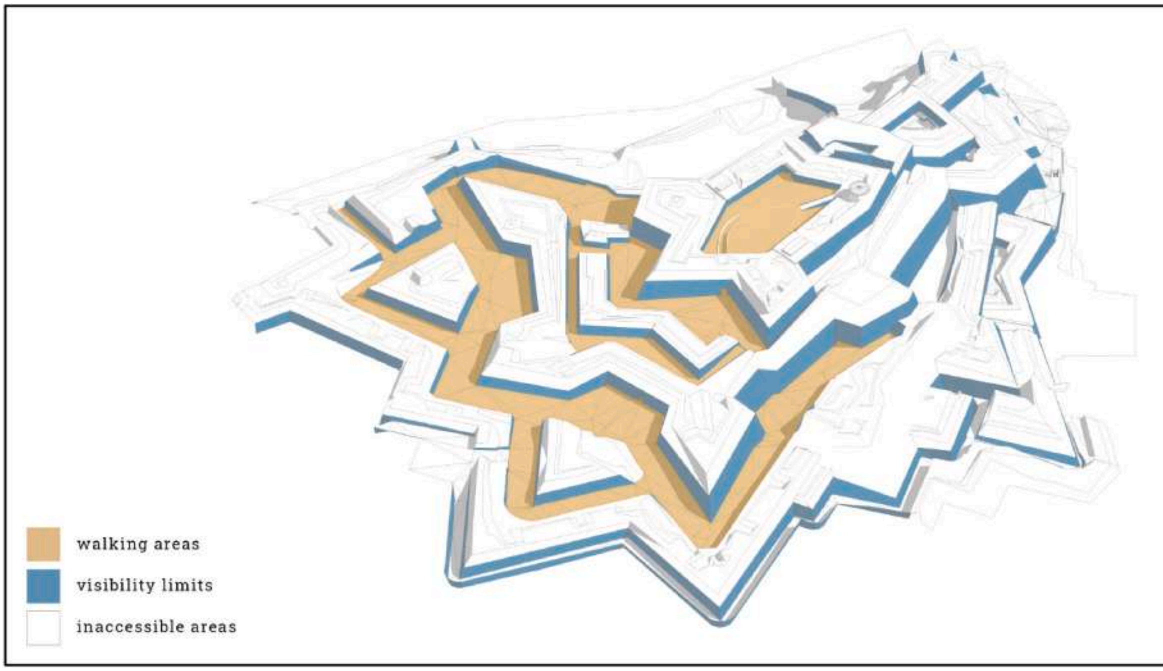


**Fig. 15.** Simplified 3D model created in Archicad (BIM software) with specified areas, exported to Unreal Engine 4 with "Datasmith Exporter for Archicad 24"– the authors' elaboration.

Open-source software, CloudCompare,[4] was used to clean and segment the point cloud.

Based on the available plan (Fig. 2b) and point cloud (Fig. 2d), a simplified 3D model was created in Archicad 24. The choice of BIM software for the modelling was dictated by the possibility of object-oriented modelling and ease of modifications and management. The properties of the objects in the form of walls, slabs and shapes were then directly used in defining visibility limits (Fig. 16), walkable areas and inaccessible zones (Fig. 15). Simplified 3D model and assigned areas are used because of the non-solid nature of the point cloud and the need to avoid an X-ray-like display (Fig. 16).

The Archicad BIM model was then exported to UE4 using the Datasmith Exporter for Archicad.[5] Using the Datasmith Exporter simplified exchanging data between platforms, preserving the information necessary for the application to run, such as scene hierarchy, metadata, materials and coordinates of Points of Learning Enhancement - PoLEs.

PoLEs (Fig. 17c) are the digital equivalents of actual information posts in exhibition spaces. This reference is also intended to facilitate user interaction and experience through discovery experience (Liu et al., 2013). PoLEs are scripted parametric objects linked with the historical database by identification number and world coordinates. Information with a unique PoLEs ID is assigned to the individual assets in the database. That allows for the flexibility of adding and removing historical data to the interaction space and presenting any media resources. In the context of cultural heritage, even a tiny information resource may expand our knowledge and change our understanding of history (Pereira Roders and Oers, 2012).

### 6.2. Application

The most crucial VSHI part is the exploring process of cultural heritage. Therefore, the user interface is simplified to a minimum, focusing on the visual message. The application of a computer game engine ensures real-time interaction and the possibility of sightseeing through space exploration. A user can move freely through the 3D space with the standard controls used in computer games - WASD and mouse to control the view and select content. As they approach successive PoLEs (Fig. 17c), they have the option to display available information from a linked database. During the tour, icons appear on the user's screen in the top left corner to indicate the resources available (Fig. 17d). These are dependent on the user's location (Fig. 17b) in space and provide treasure hints that point to places to be found. At any time, a user can click on the chosen resource and see its content (Fig. 17d) and then find it in 3D space (Fig. 17a). An essential aspect of VSHI is the natural feel and intuitive operation. Due to the similarity with the real world, even people who cannot navigate a 3D computer environment can explore cultural heritage digitally.

PoLE is built of seven modules (Fig. 17c), each allowing different information to be displayed due to its format. The resource view panel is activated by clicking on the upper cube with the letter "i", and the user can explore linked resources. Those are organised in six categories (Fig. 17c), from the left: 1. files, documents, information; 2. photographs, images; 3. archives, maps, postcards; 4. related websites; 5. 3D models, CAD files; 6. videos and audio recordings. How gameplay works can be seen in the animation attached to the article or on the website.[6]

Based on Game Approachability Principles (GAP) (Desurvire and Wiberg, 2010) we prepared an initial user experience evaluation. The online survey was conducted among professionals and people unrelated to conservation and heritage issues. The assessment was based on a ten-point rating scale for the following aspects: attractiveness, interactivity, accessibility, informativeness, intuitiveness, and usefulness with additional comments from participants. Ratings of participants professionally related to heritage and those not related were similar. Results visible on the chart (Fig. 18) suggest that the idea of the application is well received. Comments suggested increasing the visual attractiveness by using a colored point cloud. Another comment was to improve interactivity by adding sound effects, background music, or a

[4] CloudCompare https://www.danielgm.net/cc/.

[5] Datasmith Exporter for Archicad https://www.unrealengine.com/en-US/datasmith/plugins.

[6] Animation showing how the application works is available here: https://www.youtube.com/watch?v=Bn3idt3bA58.

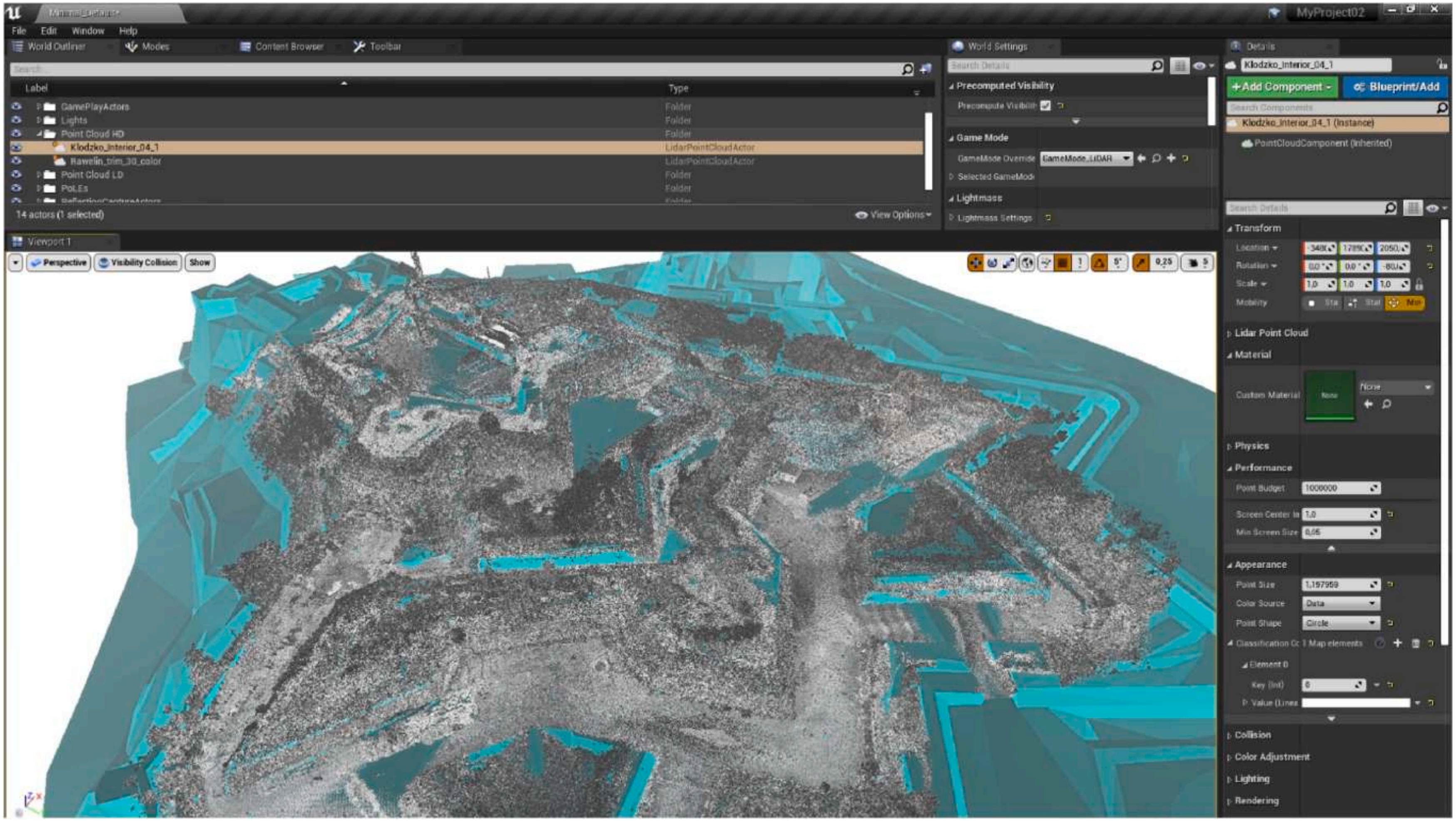


**Fig. 16.** Visualisation of the virtual setting of the Unreal Engine 4.24. In the viewport is a low-density point cloud with collision visibility displayed in cyan colour – the authors' elaboration. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

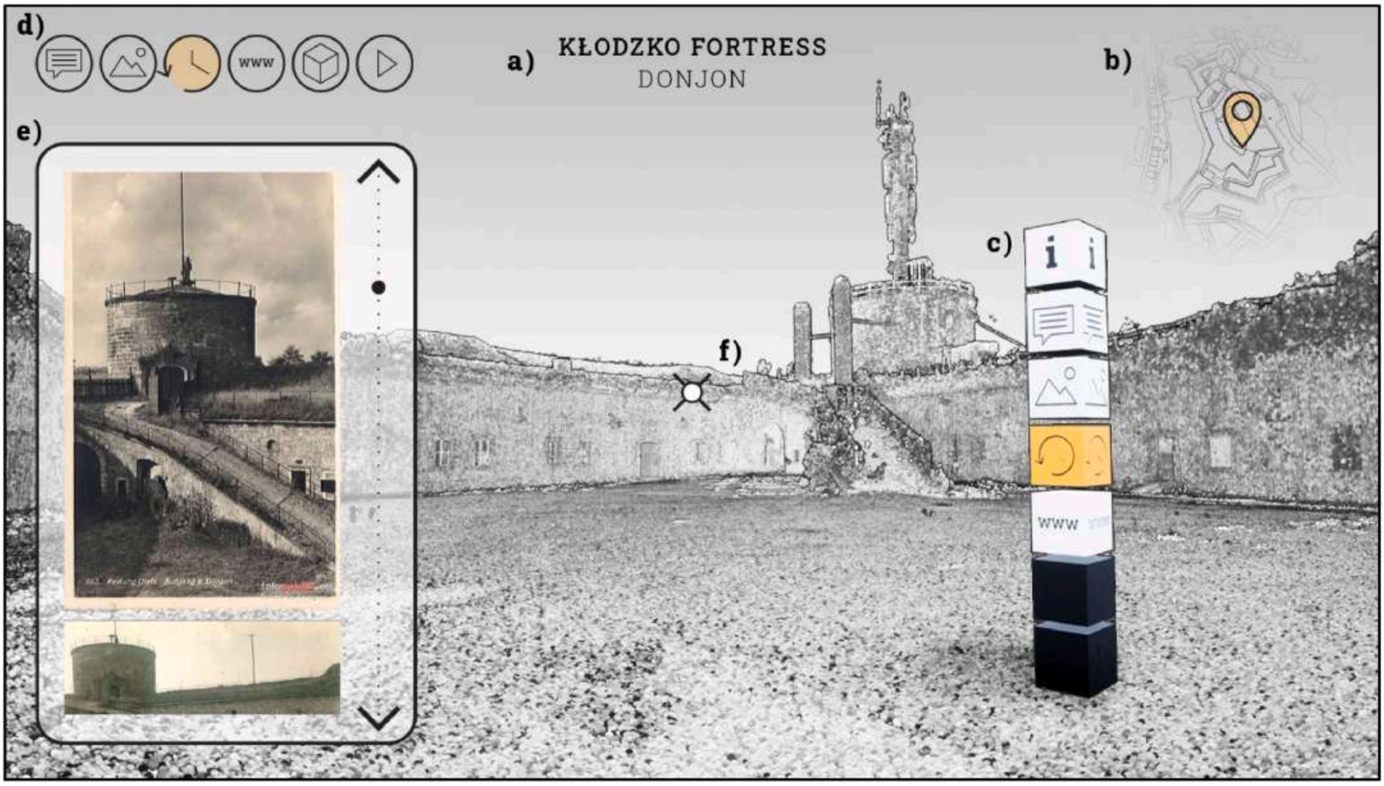


Fig. 17. Screenshot from the Unreal Engine of the Virtual Space of Heritage Interaction application. (a) site name and current location, (b) interactive minimap, (c) PoLE, (d) types of available resources, (e) resource view panel, (f) interactive cursor – the authors' elaboration.

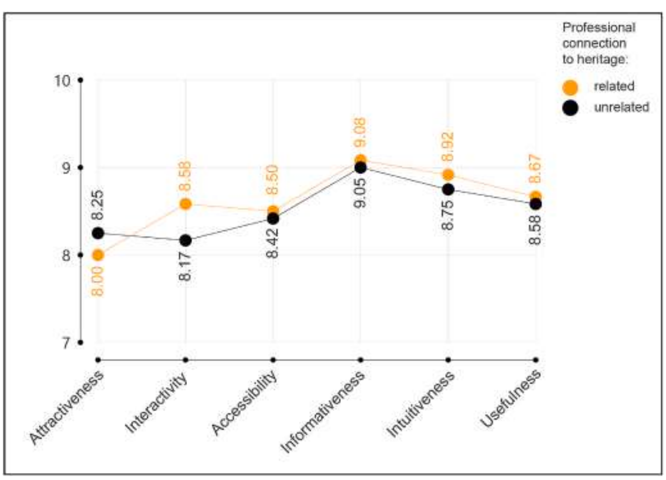


Fig. 18. Results of an initial application evaluation survey of 50 respondents.

voiceover to guide the user through the tour. The last question was whether the application encourages people to see Klodzko Fortress in person. To this question, 100% of the participants answered positively.

A final goal of the application, still under development, is to be available in the form of a website and a mobile app and be accessible to the general public. Further development would be to use it as a complement to a tour in the post-pandemic world.

## 7. Results and discussion

As a result of the project, it was possible to speed up the preparation time of the model in order to make it available to visitors to the site. Building an open, editable system was implemented, which can be developed over time and enriched with additional digital content using a linked historical database. This provides an opportunity to significantly increase the information capacity of the tool, which contributes to a better perception of the site and its setting in the historical context and building the necessary narrative. Thanks to the activities mentioned above, the object visitor, through a virtual model enriched with appropriately configured imagery, can interact more easily with multimedia products and collect and assimilate new information necessary in the cognitive process. In the presented project, the point cloud has a visualisation function as the basis of the application in addition to its prominent role as a measurement tool. Of course, with the development of computational capabilities, more and more realistic representation of reality is possible. The target of the proposed solution is to be a safe, remote tool, which in the future will enable visitors to freely explore the Kłodzko Fortress at any time and place.

### 7.1. Discussion

The ability to convey modern achievements and already existing cultural heritage is the basis for sustainable development and maintaining changes in a sustainable environment. Spreading knowledge, not only to professionals but also to society, is one of the heritage management tasks. Modern information and communication technology (ICT) raises cultural awareness and expands access boundaries (Turco et al., 2020). Applying point clouds and linked historical resources strengthen and facilitates the transfer of knowledge and the spread of learning and thus increases public awareness (Stuedahl and Mörtberg, 2012). Another aspect of using a point cloud for real-time interaction is the accurate representation of space. The actual space is shown with all its defects, not as a digitally processed 3D model, often an idealised version of reality. This underlines the importance of the conservation approach in the actual recording of space (Maiezza, 2019).

## 8. Conclusions

The possibilities of using point clouds in real-time interaction are far-reaching. However, they also have their limitations - primarily the way data is stored and its availability and computing power, which are constantly growing. The development of information technology allows for remote and mobile use of this technology, which in the future may affect the interaction of Virtual Reality, Augmented Reality and Mixed Reality in real-time with an actual visit to a place, but this is an area that requires further research.

## CRediT authorship contribution statement

**Jakub Franczuk:** Conceptualizsation, Methodology, Software, Visualization, Writing paragraph: 6.1, 6.2, Writing – original draft. **Kamila Boguszewska:** Resources, Methodology, Writing paragraph: 3, 7, Writing – original draft. **Sandro Parrinello:** Conceptualization, Supervision, Resources, Writing paragraph: 2, 8. **Anna Dell'Amico:** Software, Visualization, Writing paragraph: 5 – review & editing. **Francesca Galasso:** Software, Validation, Writing paragraph: 6, 7.1, Writing – review & editing. **Piotr Gleń:** Methodology, Data curation, Investigation, Writing paragraph: 1, 4, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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