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The example of applications of new digital documentation technologies based on the archaeological research conducted at the Royal Castle in Warsaw – the critical analysis

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Abstract: Technological development does not go unnoticed in historic preservation. There is a search for new solutions and concepts through which the protection and management of cultural heritage would become more effective and optimal from the point of view of various stakeholder groups. This article aims to present new opportunities brought by applying modern techniques in creating documentation of architectural and archaeological research. Particular attention has been paid to the multifaceted possibilities of subsequent use of the acquired data. The example of the Royal Castle in Warsaw served as a starting point for considering a wide range of applications in various fields related to the protection of cultural heritage. Potential inventory and analytical, as well as popularisation solutions, were presented. The potential of modern technologies continues to be discovered, and their use in the protection of cultural heritage is slowly becoming an everyday reality.

Keywords: analysis; archaeological excavations; cultural heritage; inventory; new technologies; protection

1. Introduction

The protection of cultural heritage has been and continues to be the subject of much discussion in international and local forums. Many legal regulations, documents or international conventions signed by authorities from the world of science, culture or politics have been created [1–7]. Despite disputes over the method of protection or methodology, the goal remains unchanged: to preserve the cultic heritage for future generations [8].

With the development of technological thought, researchers have acquired new tools that make the documentation and analysis of ongoing work on a monument more efficient [9–16]. The obtained data have lost their subjective character, and, most importantly, the mappings are fully realistic. The universality and, at the same time, the indispensability of these tools are confirmed by the provisions of the Krakow Charter, the document summarising the International Conservation Conference "Krakow 2000", which proclaims that "in the protection and public presentation of archaeological sites, the use of modern information technology, such as databases, multimedia presentation systems, and virtual reconstructions should be promoted" [17]. Access to cultural heritage resources has become more widespread giving the public the opportunity to enjoy cultural assets in many ways. The needs for innovative and creative services are being met, using the products of various fields, such as other cultural or creative sectors, as well as tourism. As highlighted in "Digital Compass for 2030: Europe's path in the digital decade" [18], digital technologies have

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become more than ever indispensable for work, learning, socializing, entertainment, and access to a wide range of services and products, from health care to access to culture.

Unfortunately, despite the expanding range of newer solutions and tools, using their capabilities is not always possible for field researchers. The most significant drawbacks are access to specialised equipment and the cost of hiring specialists. Also, a problem is the ability to correctly select a documentation method and correctly analyse the result of the performed investigations. Therefore, in many cases, researchers are inclined to traditional investigation methods. The traditional measurement of even the most straightforward and accessible monument is not, in effect, a complete measurement. It uses only a certain number of characteristic points and then requires completion, usually by hand, of the remaining data. This reduces the accuracy of other unmeasured points. In the case of a complex site, accurate measurements are limited only to making detailed documentation of characteristic nodes and locations necessary for further analysis. Other information is limited to descriptive and photographic documentation. Detailed documentation of the entire site is too time-consuming and sometimes expensive. The resulting image is, therefore, a subjective representation, subject to human error [19].

In recent years, however, a breakthrough has been evident; many researchers are reaching for new technological tools, recognising their advantages, namely, Terrestrial Lasser Scanning or close-range photogrammetry [20–23]. In addition to the high accuracy of measurements, they are causing an acceleration of the pace of work, and using various reconnaissance techniques is reducing costly excavations to a minimum. Interpretive possibilities also increase by obtaining more data. The combination of multiple survey methods allows one to confront data from different scientific disciplines. Thus, an image is created that is a permanent basis for all registrations and interpretations, for the needs of several fields of science simultaneously [24].

However, using terrestrial laser scanning or close-range photogrammetry in the documentation does not eliminate the need to interpret the layering in the field. For the archaeologist, it is essential to document the various stages of the work with the possibility of reconstructing them later. The study of archaeological sites involves the exploration of successive cultural layers. Removal of subsequent levels involves their irreversible destruction without the possibility of reconstructing the original layouts. Detailed, ongoing documentation is, therefore, essential. Inventory measurement is a document of archival importance that contributes to the study of the culture of a given period, is an indispensable supplement to historical documentation, and is the basis for the development of preservation, restoration, or reconstruction projects.

Ongoing analysis of the complex stratigraphy sometimes changes the methodology adopted to adapt to the prevailing circumstances. The use of modern documentation methods also causes a partial change in how excavations are conducted.

When applying modern documentation techniques, however, it should be assumed that they are not an end in themselves but will result in perfect documentation for scientific interpretation. The overriding goal should be the verifiability of applications based on internally consistent documentation, as faithfully reflecting the real image as possible, with a known, constant margin of error.

This article aims to critically analyse the possibilities of using modern survey technology in archaeological work. As an example, the results and measurement documentation produced by terrestrial laser scanning technology and close-range photogrammetry used to inventory the progress of archaeological works are presented.

2. Materials and Methods

The research at the Royal Castle in Warsaw (Fig. 1) will serve as an example of the application of new technologies. This kind of research field is challenging to observe. Over

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the centuries, the site has undergone numerous transformations that blurred the image of the past. The Castle has been subject to innumerable reconstructions and expansions, making accessibility of some areas less or impossible, using traditional exploration methods.

Figure 1. The view of the Royal Castle in Warsaw.

The Castle became a training ground for the detailed study of architecture and archaeology shortly after World War II. The residence was destroyed during the Warsaw Uprising in 1944. Nevertheless, some architectural structures survived. This is especially true of the foundations and basement rooms. Despite its lack of material presence, it continued to function in the public consciousness, which led to the start of the unique work of restoring the former Warsaw royal residence. The planned reconstruction work was the reason for undertaking extensive research.

Paradoxically, the destruction of the Castle's body made it possible to plan thorough research. The reconstruction of Warsaw, destroyed during the war, became a unique opportunity for architects and archaeologists to solve many problems concerning the history of the city and the Castle. Unfortunately, mixed results were influenced by the time's political and social relations. Leaving aside the political complexities, it should be said that this was pioneering research during which the knowledge of representatives of various scientific fields was used. During the architectural inventory, specialists from the Warsaw University of Technology, among others, cooperated using photogrammetric documentation. For the first time, geological drilling was used to analyse cultural layers. The research at the time provided a solid foundation for the ongoing process aimed at clarifying the origins of the Warsaw castle. The process continued with the latest archaeological research conducted in the vicinity of as well as inside the 14th-century Justice Court Tower, the oldest surviving masonry building that is part of the castle complex. The Tower and its surroundings were the research subjects in the years of reconstruction, but the scope of the study was minimal. It did not answer many questions related to its construction or connections to the other buildings. Thorough research was conducted in 2017 and 2018 on the occasion of the Tower's renovation.

The research area included excavations in the Tower's interior and western outer wall. The goal was to obtain a complete knowledge of how the Tower was founded and the technological solutions used during its construction. Since the research was carried out in parallel with the construction work, the time for making a detailed inventory was minimal. It became necessary to use rapid documentation methods. The project envisaged creating a complete, integrated digital documentation created gradually at different stages of

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exploration. Exploration was carried out at other times and under different weather conditions. In some cases, accessibility to the surveyed elements was also a problem, prompting researchers to apply different documentation methods and use different measuring tools.

To this end, as part of the inventory work, it was decided to acquire ground-based point clouds using terrestrial laser scanning (Terrestrial Laser Scanning; Z+F 5006h scanner) and a series of close-range images processed using the integrated Structure-from-Motion and MultiView Stereo method. The generated point clouds served as the egg basis for architectural and archaeological documentation in the form of orthoimages and 3D models. The use of multisensor data allowed the elimination of errors occurring during measurements by the terrestrial laser scanner and those appearing in the results of processing close-range images by the above methods, which enabled the creation of a comprehensive profile of the studied area and the production of complete documentation of archaeological excavations.

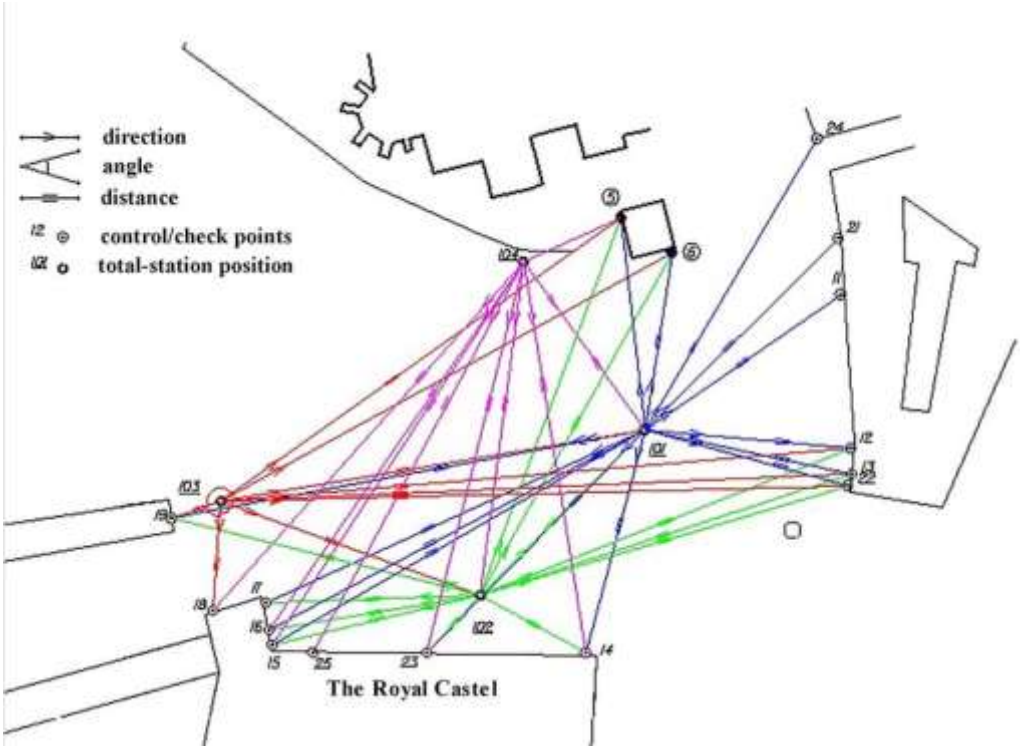

Figure 2. The example of a geodetic network (first-order) used for data orientation [25].

A geodetic points control network (considered a reference system) was designed and established as the first part of this investigation (Fig. 2), and it was a base for multisource data registration. Due to the multi-phase dredging of the archaeological excavation and the impact of these works on the immediate surroundings, it was decided (at different survey epochs) to control and analyse points displacement. It should be emphasised that this was a novel approach, previously not used in archaeological measurements using geospatial methods, allowing to increase the accuracy of the final architectural and archaeological documentation. Based on the above-mentioned photogrammetric matrix points, the process of orientation and processing of ground photos was carried out, which included: photos taken with a Canon 5D Mark II camera) and a low-cost sensor, Canon PowerShot G5 X. Agisoft PhotoScan software was used for the orientation and processing of close-range images, and LupoScan software was used for TLS data. The processing and registration of images and TLS data resulted in point clouds in an external datum. These data were used to

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study the thickness of the walls of the Justice Court Tower, analyse the foundations, and generate orthoimages used in the chronological analysis.

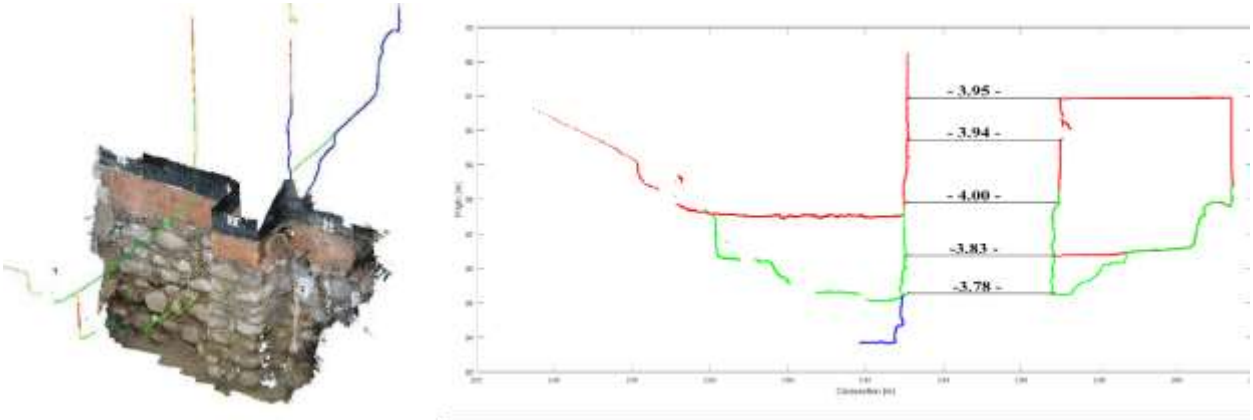

Figure 3. The example cross-section with marked measurements [25]

The generation of a complete profile of the site (Fig.3), obtained from two lines placed on either side of the Tower's western wall, made it possible to trace the sequence of the construction process, from the preparatory phase to the full implementation of the project. The east side of wall A reveals the stepped structure of the Tower's northern foundations, which were built on the slope of the hill that forms the structure's base. As a result, the stone base of the eastern wall is lowered to a height of about 1 meter. The difference in the level of the foundations of the opposite walls is about 2.5m. Holistic documentation of the investigated site (Fig. 4) was obtained by adapting the method of documentation to current conditions in the course of the work, along with the possibility of data integration [25].

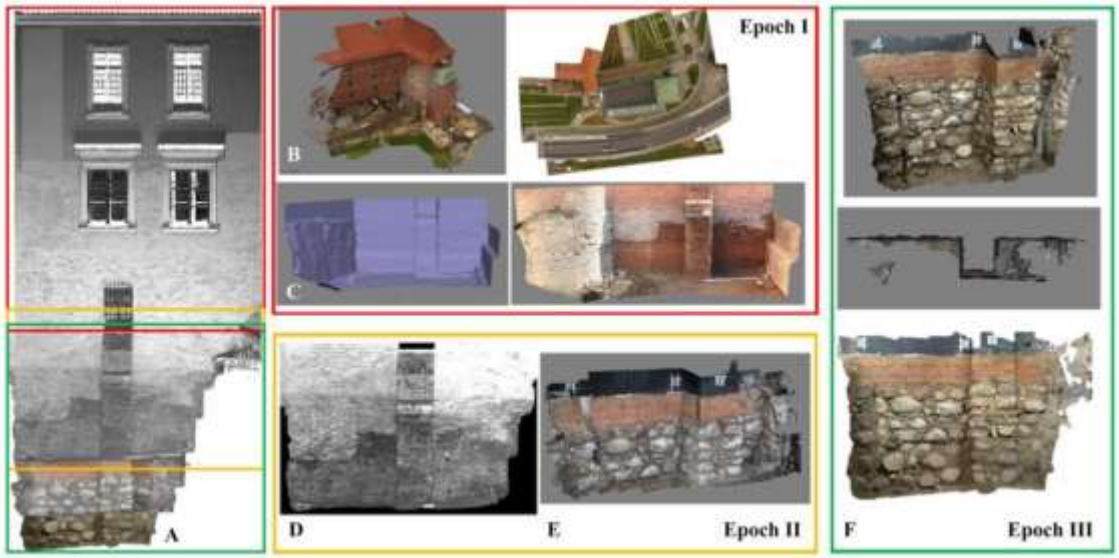

Figure 4. Results of integration of multitemporal data: A) the combined multitemporal image, B) the 3D model 3D and true- orthophotomap (Epoch I), C) the 3D model and the RGB orthoimage for the upper part of the excavation (Epoch I), D) the intensity orthoimage from TLS Z+F 5006h, and E) the 3D model from images of the central part of the excavation (Epoch II), F) the 3D model and the RGB orthoimage for the bottom part of the excavation (Epoch III) [26]

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3. The critical analysis of the possibilities of modern measurement techniques for archaeological surveys at the Royal Castle

The creation of digital documentation, in addition to its undoubted advantages, also carries certain risks, awareness of which should influence the actions taken. As mentioned, the measurements' precision can be significantly falsified if we do not implement control procedures.

An example of this is the created geodetic network, which provides the possibility of using georeferenced data in a single assumed datum. The analysed object is inscribed in a broader spatial context, which allows for comprehensive geometric and topological analyses and easier planning of subsequent archaeological survey work in a specific area. However, it should be remembered that monitoring benchmarks (control points) in urban areas is crucial. Increased activity in the urban environment can cause the displacement of points, so it is important to control them so that, in the end, there are no problems adjusting the data into the adopted reference system. The correctness of the measurements is affected by many factors, one of which may be the geological conditions prevailing around the objects. Therefore, it is recommended to adopt surveying techniques that allow for building displacement analysis. The initial condition may change due to, among other things, deformations or slight movements of objects.

Another aspect is the 3D models presented in the article, generated to conduct spatial analysis. They definitely broaden the research perspective and can serve as a promotional measure. The pitfall in acquiring this type of data can be its quantity. Before creating this kind of documentation, it is necessary to consider what final result we are interested in and what will be used for further work. Generating a massive amount of data can paradoxically reduce the cognitive element by blurring what is most relevant to the aspect being studied. The wide range of possibilities of digital documentation must pass through a filter of sorts to adapt to actual needs. The selection of these procedures is closely correlated with the object, the purpose of the measurement, and the researcher's expectations and needs. In the case of the research conducted at the Royal Castle, digital terrain models were mainly used to make cross-sections of the site oriented in any direction. On the other hand, the orthoimages were used to analyse chronological differences by making interpretive layers. They are also excellent presentation material to illustrate the positions and objects at exhibitions and a means of enriching publications.

Terrestrial laser scanning is subject to various measurement errors like any other measurement technology. In the course of field surveys carried out in variable weather conditions, which often significantly reduce visibility, the precision of measurements is compromised. Also, access to the monitored surfaces is sometimes limited. In the case of complex objects with many refractions, the difficulty is the proper positioning of the instrument. The method used at the Royal Castle in Warsaw of combining different means of documentation proved optimal. Performing classical documentation, in this case, would have led to the creation of a considerable number of documents, for the development of which a large amount of time and labour would have been required. The most important advantage of vector images is their scalability. They can be enlarged unlimitedly, and their aspect ratio can be changed without compromising quality, as they are mathematically recalculated each time. Vector images can be transformed into their raster counterparts, but their quality is lost. Vector graphics describe three-dimensional space - that is, geometry and its transformations are described using vector graphics methods, while the appearance of objects is defined by transforming them into the raster form. The disadvantage of vector graphics is that it does not provide photographic fidelity of reproduction.

The high rate of development of digital technologies in the documentation of historical objects makes it challenging to implement them and take advantage of all the

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opportunities they offer. Mastery of new techniques and computer programs by specialists in the humanities is a challenge for which they were often unprepared during their studies. This is where the need to increase competence and further training in new technologies comes in.

4. Conclusions

The biggest concern of archaeologists conducting research related to the investment is time pressure. To maintain appropriate standards, it is necessary to adapt the research method to the existing conditions. The method of interpretation always remains the same. The most important thing is the researcher's knowledge of the object under study and substantive preparation for the project. He decides which data he will use and to what extent. Data analysis remains the responsibility of the researcher—only the method of recording the data and its universality changes.

The universality mentioned above of documentation created with modern measurement technologies makes additional possibilities beyond its scientific dimension. Comprehensive, easy-to-process information can be used in popularisation work [24]. With the growing importance of modern technologies, the sensitivity and expectations of the viewer are changing. Modern museology has faced the challenge of adapting to new trends.

The 3D scanning technology provides a new unprecedented opportunity for 3D measurement of museum exhibits. It makes it possible to create virtual museums, publish 3D objects on the Internet, and research exhibits. Digital collections or exhibitions are becoming increasingly popular. The existence of museums in the online space is increasingly visible, not only through websites. Social media plays one of the leading roles, where not only basic information is published, but various kinds of digital products: videos or 3D renderings. They provide a communication platform between the museum, as an institution, and the recipients of the presented content.

One form of making culture available online is the digitisation of collections. Increasingly, electronic catalogues are being created and made available online, presenting the museums' resources at different levels and tailored to the commercial or professional user.

Digitising collections is also a form of preservation. Cultural assets are protected from degradation by creating digital copies (now a widely discussed issue concerning digital twins). By creating digital documentation, in many cases, a permanent image is drawn up of an object that, for various reasons, is no longer available. During the previous archaeological research at the Royal Castle in Warsaw, conducted on the occasion of the renovation of the Justice Court Tower, an orthoimage of the entire western façade was made, from the base of the foundation to the roof. This is the only document with a complete image of the wall combined with original and rebuilt elements. Such an inventory was only possible during the research because the chosen methods of insulating the wall assumed permanent covering of the historical elements with insulating material [26]. The production of such documentation provides the opportunity to return to the analysis in case new facts emerge. Although the lack of physical accessibility to the object under study, a detailed and accurate mapping with metric properties can provide the basis for analysis, research, measurement, investigation, comparison, and synthesis.

The study of these models and how they can be used depends on the needs. In a museum setting, in addition to research purposes, the resulting model can be used in the creation of exhibitions and thus be used for educational activities.

The above-described examples of applications of new technologies to the study of architectural monuments are only a hint of the possibilities of their use. The digital world,

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which is developing at a rapid pace, undoubtedly has an impact on the qualitative perception of reality. The use of new solutions makes the work more efficient through better use of existing resources

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