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ADVANTAGES OF USING 3D SCANNING IN THE SURVEY OF ARCHITECTURAL MONUMENTS ON EXAMPLE OF ARCHEOLOGICAL SITES IN EGYPT AND RUSSIA

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Every conservation works related to an ancient masonry structures should be preceded by an appropriate diagnostic. This should be understood as geometrical survey and various tests, which results with a proper analysis of the structure, identification of materials, technologies and techniques used during construction. The effective tool which could be used in this field is 3-D laser scanning. The digital image obtained as a result of scanning could be a proper base for a preservation programme, as well as help for creation of a precise digital models for a structural analysis. The examples of 3-D laser scanning application presented in the article are diagnostic works carried by the Division of Fundamentals of Building, Warsaw University of Technology, with the cooperation of Warsaw University, at the archaeological sites in Alexandria, Egypt and in Tanais, Rostov, Russia. Based on this works some most important advantages of laser scanning in identification, diagnostics and preservation of ancient architectural monuments was stated.

Keywords: Laser Scanning, Archaeological Heritage, Masonry Structures

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1. Introduction

Complete, properly-made geometrical survey and documentation constitutes one of the most basic questions connected with architectural conservation. Archaeological research and documentation of its results is of great importance, particularly in the case of monuments, which often require excavation works. Properly-made documentation makes it possible to identify materials and technology used for construction, which constitutes the basis for correct conservation works' strategy [1]. Correct diagnosis of historic masonry structures constitutes the basis for the effectiveness of all other activities related to their maintenance, strengthening, rehabilitation and preparation for their later exposure. Detailed identification of materials, technology and techniques for the construction of historic building, as well as a proper understanding of load bearing structure and the work resulting from real static scheme should be a part of this diagnostic. In the case of ancient buildings, we often deal with techniques and technologies not used today.

Masonry elements forming historic masonry structures often differ in their material properties (stones of different mineral composition, derived from different rocks, dried bricks, ceramic bricks, etc.), physical properties (gravity, density, tightness, porosity, weight and volume absorbability, rate of saturation, thermal conductivity, thermal capacity, freezing resistance, fire resistant) and mechanical properties (strength, hardness, abrasion and impact-resistant), as well as in overall dimensions and shapes (large and small elements, sortable and non-sortable stones, rectangular or with complicated shape elements).

Identification of materials, masonry elements, kind of join between elements, their shapes, physical and mechanical parameters has multi-faceted significance for the monument that goes beyond the architectural, structural or conservative aspects. Proper identification of materials and technologies used is also important in terms of historical, cultural, aesthetic, environmental, social or even economic impact.

The conservation aspect shows the relationship of the originally used materials, techniques and technology with activities aimed at securing and preserving the monument, inhibiting its destruction, and documentation of these activities.

The architectural aspect shows the impact of applied materials and technologies on form of the building, an architectural-functional system, canons, and styles of the particular historical period. The architectural aspect is closely related to the aesthetic one that results from the definitions of beauty of the given periods of time, but that always has the element of subjective assessment.

The structural aspect of proper identification of the materials and technologies used in the construction of a particular historic building is of fundamental importance. The proper recognition of the construction technique used, the physical and mechanical properties of the materials used gives the possibility of proper assessment of the technical condition of an construction or its fragment, proper determination of load bearing structures work, including issues connected with structural rigidity of historical buildings. Awareness of destructive processes occurring during the existence of the construction and changes in natural environment, create the need for conducting diagnostic tests also in the environmental aspect.
The historical aspect relates to proper material and technical diagnostics in the context of architecture and construction history, including the proper recognition of construction techniques and technologies closely related to the art of building applied in a given region, during a specific historical period. The historical aspect is closely related to the cultural one. Construction and architecture are always part of culture being a manifestation of a particular civilization. The findings concerning ancient monuments result from archaeological, architectural, construction and conservation studies and analyses. They are usually crucial for further conservation and rehabilitation works.

2. LASER SCANNING

Laser scanning 3D is a modern and dynamically developing measuring technology that has many uses in engineering and research. The Faro 3D Focus laser scanner was used to make a comprehensive geometric inventory of the excavation site. The result of 3D scanning is a collection of measurement points defined in the Cartesian system, called a point cloud. It is also important to note that when measuring outside the XYH spatial coordinate, the fourth parameter, reflection intensity, is obtained. Each surface is differentiated by different laser beam reflection characteristics. This is particularly important as seemingly uniform and even surface, may in the view of the characteristics of reflection show differential areas (e.g. different humidity, chemical composition, etc.).
Definition of the scanner's attributes is done by selecting the appropriate settings for the type of scanned space. During the archaeological research one of the record techniques was used. The data from different scanner stations was combined using cloud to cloud method. It consists in finding homologous surfaces on different sets of data and combining them by interaction method.
An important advantage of using 3D scanning in archaeological research is measurement range. The technology allows the device to operate from 50 cm to 330 m (Faro Focus X300). With the highest scan parameters, it is possible to reach resolutions up to 1mm at a distance of 10 meters from

the scanner. It allows to measure fractures and defects in the structure of a building in hard-to-reach places. Additional the non-contact and non-invasive nature of 3D laser scanning makes it ideal for sensitive objects such as architectural monuments. Damage, disruption and displacement of sensitive items in situ is an almost not existing risk.

The measurement data obtained by the laser scanner is of high accuracy. The 3d scanner uses a single point accuracy of +/- 2mm at a distance of 50 meters from the scanner at a measurement speed of up to ~ 1mln per second. In comparison, a conventional documentation techniques allows to obtain drawing with centimetre-range of accuracy, that strongly depends on skill of the person who prepares it [2].

Mass measurement of the geometric characteristics of the excavation site allows for a detailed investigation of the residue of the structure of the site. 3D scanning reduces the measurement time in relation to classic measurement techniques several times. In case of the architectural structures, time required for data acquisition can be reduced even by 75%. It was described in [2] based on the studies of the church of Valberzoso (Palencia), where the usage of 3-d laser scanner reduced field work days from 9,5 to 2,5. Moreover, it also led to reduction of office working time – from 26 days with conventional methods to 19 days of work on the data obtained from laser scanning.

3d scans of the site were done in colour . Thanks to the built-in camera, it is possible to colour point cloud obtained in the first stage with images. Images taken by the scanner, once assembled, create a 360 panorama. Such imagery can be used to visualize the state of objects in the excavation site.

The advantage of digital geometrical survey is the integration of various types of data. By default received data is defined in a local cartesian coordinate system. 3D measurement data can be subjected to any transformation of the datum. By using the built-in GNSS scanner and compass, it is possible to placed measurements in the geodetic space [3-7].

3. ANALYZED HISTORICAL STRUCTURES

3.1. Corridor constructions in Alexandria, Egypt

Detailed documentation of monuments is of great importance in the diagnosis of ancient structures, in which all studies should be performed "in situ". A good example is the research conducted in the late antique (4th century AD) underground structures located at excavations at Kom-el-Dikka in Alexandria, Egypt. Long-term archaeological research is conducted under the supervision of Grzegorz Majcherek from the Center of Mediterranean Archeology at the University of Warsaw. The subject of diagnostic research was underground construction, which is a complex of corridors, forming an orthogonal net – Fig. 1. They are made of lime ashlars in wedged shape forming barrel vaults. At a crossing barrel vaults forms a cross vault.. It is a unique and original system, not commonly used in late antiquity. There is no reference of such a structural system among any preserved structures. The technical condition of these structures and the preservation degree is varied. On the large area, the corridors were destroyed by Roman baths constructed on them later on. Fragments of the vaults are ruined, damaged and cracked. We can observe buckling of arches and local, excess deflection. Diagnosis of these constructions, designed to develop a strategy of their protection, reinforcement and reconstruction, required a very thorough geometrical survey and analysis of the system and particular masonry components.

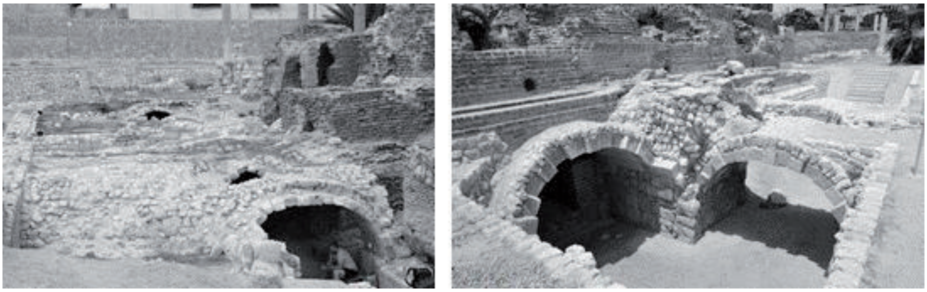

Fig. 1. Corridor constructions in Alexandria, Egypt

In the first phase, visual inspection of the structure and macroscopic examination was performed as well as photographic documentation, including survey of the worst damages. The width of the cracks in the structure is also very different - from a few millimetres to more than one centimetre, depending on the location. In some placed, the structures are mechanically destroyed, degraded biologically, salt efflorescence and granular disintegration are visible.

The cause of progressive biological degradation of the structure is dampness, resulting in locally severe salt efflorescence and stone delamination. Due to the complex shape of the structure, in the areas of crossing barrel vaults, it was necessary to thoroughly analyse the shape of vault, the particular areas of vault, walls and masonry. For this purpose, laser scanning 3d was used. The results obtained, together with laboratory tests determining the physical and strength parameters of the masonry elements and mortar, provide the possibility of a thorough preparation of conservation program and reconstruction of ancient underground structures.

3.2. MASONRY STRUCTURES IN TANAIS, RUSSIA

The second place of research was the ancient city of Tanais, now at the mouth of the Don River, and originally, probably on the Sea of Azov. Archaeological works have been carried out there since 1995 by two institutions of the University of Warsaw - what then was named Archaeological Research Center of Novae (now Antiquity of Southern Eastern Europe Research Center) and the Institute of Archeology. The city of Tanais was founded at the beginning of the 3rd century BC by Greek settlers and existed until the middle of the 3rd century AD, when it was probably destroyed by Sarmatian tribes. Since 1999, Polish research has been carried out in excavation XXV located in the western part of Western Tanais. The initial purpose of the work was to verify route and structure of a west fortifications, but next to city gate, stone and wood bridge was discovered, a unique engineering work in the ancient world, and a detailed archaeological work was begun in its surroundings. During these works, irregular, clay mortar, masonry walls were discovered, which were the subject of our research. [8,9].

Fig. 2. Structure of the wall

Macroscopic investigations conducted during excavation showed that masonry structures were made of rubble and rounded stones, mostly unsorted, differing in structure, sedimentation, porosity and absorbability and, which is closely related to that, degree of humidity. In the structure of the wall we can distinguish larger stones forming the cladding of the wall and small stones that constitute its filling. The walls binder is a clay mortar, based on clay and sand located in the surrounding ground. Walls of this type have low strength, cohesion, as a result, poor durability [10, 11].

The walls are visibly damaged (Fig. 2). Some types of rocks from which masonry walls are made show visible granular disintegration. The structure of the walls is degraded to a large extent, which in addition to possible conscious human influences, is a result of destructive environmental processes.

Water in the clay mortar masonry walls is especially dangerous. It penetrates in the inside of the wall, causing swelling and weakening of masonry elements.

In this case, it was necessary to develop a conservation programme for these elements. Detailed identification and survey allows to formulate preservation programme, which includes reprofilation using anastylosis technique, which preserves original bounding and layout of units.

4. LASER DIAGNOSTIC OF A STRUCTURES

4.1. LASER DIAGNOSTIC OF A STRUCTURES IN EGYPT

Based on laser scanning conducted in June 2015, an attempt was made to map the original shape of the corridor structure. Interesting part was the most damaged intersection of two corridors - Fig. 3 fragment a and Fig. 4.

In Figure 4, the cross-vault damage in the analysed part is clearly visible. Part of crossing barrel vaults is damaged too. This can endanger the stability of the system.

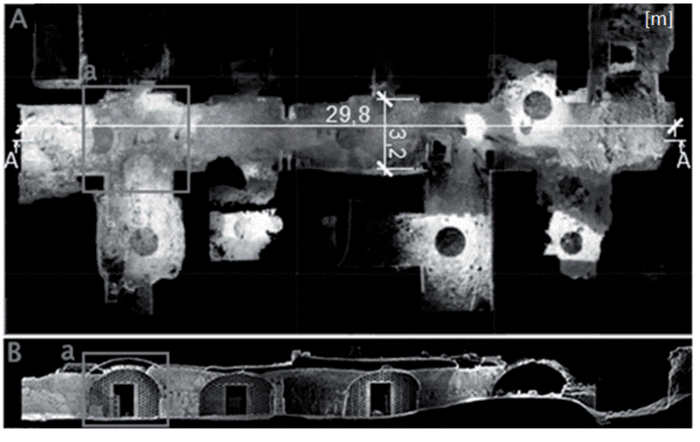

Fig. 3. Laser scanning images: horizontal projection (A) and longitudinal section A-A (B) of corridor structures in Alexandria; a – analysed part

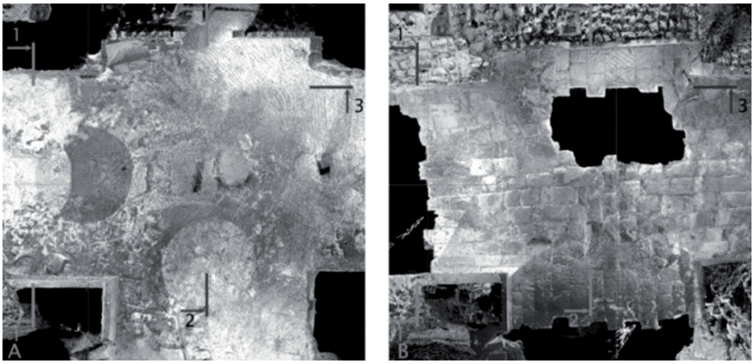

Fig. 4. Laser scanning images: horizontal projection (A) and view of the vaults from below (B) of the analysed part marked on Fig. 3 with specified cross-sections

As a representation of the original construction, it was possible to adjust arc of a circle of radius 1,65 m and bow 1,5m on the basis of cross-sections obtained from laser scanning (Fig. 4). As seen in the cross-sections, the shape of the vaults is aligned with the probable original shape, deformation of the main hall vault of between 0,2 m and 0,4m is, however, clearly visible. This may indicate the likely overload of the vault that might have occurred in the history of the structure. Definitely a greater [m] deformation of the edge of hole is probably due to damage of the vault, thus the existing part has lost its support.

Based on the cross-section of Fig. 5A, the thicknesses of individual vault layers can also be determined. The main structural part made of stone blocks is about 0.2 m thick, while the outer layer of clay mortar and small stones has a thickness of about 0.3 m.

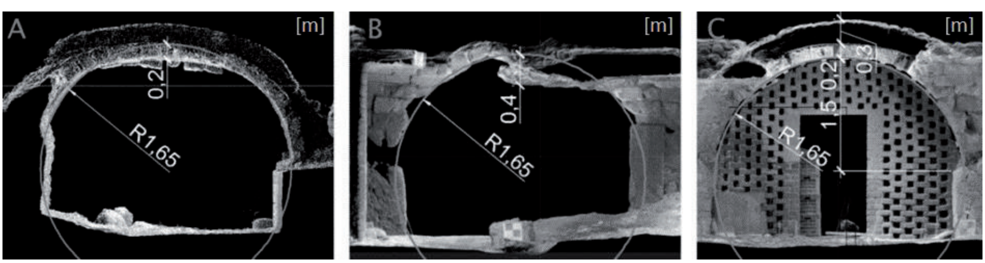

Fig. 5. Laser scanning images: cross-section 1-1 (A); cross-section 2-2 (B); cross-section 3-3 (C)

Using the above measurements and assumptions, it was possible to create a digital model for FEM analysis.. This type of analysis can be used, for example, to confirm the hypothesis of excessive deformation of the vault due to its overload. However, in order to ensure the reliability of the results, it is necessary to conduct material research to determine the strength properties of the walls, and in particular their properties in the field of non-linear analysis.

4.2. LASER DIAGNOSTIC OF A STRUCTURES IN RUSSIA

What is typical, for wild and semi-wild walls an examined element is characterized by a varied geometry of stone elements and by their arrangement. Geometrical survey of such a system with the use of traditional methods presents great difficulties. In order to minimize the number of inaccuracies, laser scanning method was selected. Examples of results are shown in Fig. 6.

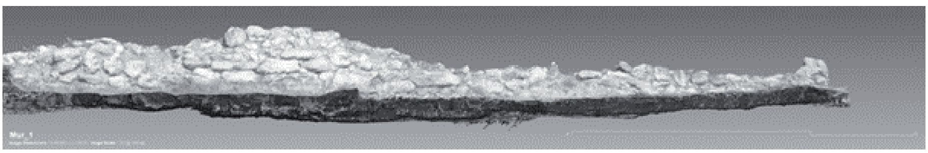

Fig. 6. Laser scanning image of masonry structures

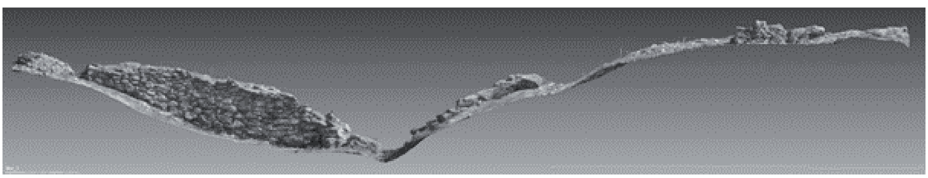

Fig. 7. Laser scanning image of cross-section of the excavation

Performed macroscopic and geometrical surveys in the form of 3D laser scanning as well as photographic and photogrammetric documentation constitute the first stage of examination of these constructions. They are the basis for a thorough analysis of technical condition of the structure and a conservation program. The next step will be the protection of damaged sections of the walls and conservation, including reprofilation and strengthening, based on the authorial method used before by authors and verified in the conservation missions conducted in Tyritake, Ukraine [10, 12].

5. CONCLUSION

Diagnostics of ancient monuments requires careful structure survey and load bearing structure identification. It is particularly important to create an accurate geometrical survey of cracks, damages and deflections of load bearing structure. The specifics of ancient objects as a part of archaeological excavations are periodic access and the ability to conduct research and measurements, which makes it difficult to verify the results of previously acquired measurements and research. In such cases, it is necessary to prepare a documentation that will be verifiable without access to the object under investigation. An extremely useful tool for this type of task that becomes more and more frequent is laser scanning, which allows for a detailed analysis of the surveyed structures' shape, as well as measurements of deformation and damages in digital environment. The results of laser scanning also provide the basis for quick and very accurate numerical models that may constitute the basis for further static-strength analyses. All most important advantages of laser scanning in terms of identification, diagnostics and preservation of ancient architectural monuments are listed in table 1.

Table 1. Advantages of laser scanning in identification, diagnostics and preservation of ancient architectural monuments

	ADVANATGES
1	High accuracy of data obtained by the laser scanner
2	Possibility of measurement of fractures and defects in the structure of a building in hard-to-reach places
3	Detailed investigation of the residue of the structure of the site by mass measurement of the geometric characteristics of the excavation
4	Reduction of measurement time in relation to classic measurement techniques
5	3d scans of the site in colour
6	Visualization the state of objects in the excavation site by 360 panorama created by images
7	The non-contact and non-invasive nature of 3D laser scanning makes it ideal for architectural monuments

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LIST OF FIGURES:

ZALETY ZASTOSOWANIA SKANINGU LASEROWEGO W BADANIACH ZABYTKÓW ARCHITEKTONICZNYCH NA PRZYKŁADZIE STANOWISK ARCHEOLOGICZNYCH W EGIPCIE I ROSJI

Słowa kluczowe: Skaning Laserowy, Zabytki archeologiczne, Konstrukcje murowe

STRESZCZENIE:

Wszelkie działania konserwatorskie dotyczące starożytnych konstrukcji murowych powinny być poprzedzone dokładną diagnostyką. Można tutaj wyróżnić działania pomiarowe i różnorodne badania, mające na celu dokładną inwentaryzację analizowanej struktury oraz identyfikację materiałów, technologii i technik użytych w procesie wykonania, które często są współcześnie zapomniane, niestosowane lub zupełnie nieznane. Właściwa interpretacja otrzymanych wyników może przyczynić się do opracowania skutecznego programu konserwatorskiego, mogącego zawierać nie tylko działania zabezpieczające i wzmacniające, ale również rekonstrukcje, zarówno rzeczywiste jak i wirtualne. Efektem tych działań może być również stworzenie wirtualnego obrazu zabytku, zawierającego wszystkie dane o nim. Może to przyczynić się do zachowania zagrożonych obiektów światowego dziedzictwa kulturowego w rzeczywistości wirtualnej. Skutecznym narzędziem do tego typu diagnostyki jest skaning laserowy. Obraz numeryczny uzyskany ze skaningu, z wielością danych, które zawiera, jest podstawa stworzenia skutecznego programu konserwatorskiego, a także daje możliwość wykonania dokładnych, numerycznych modeli badanych konstrukcji, wykorzystywanych w obliczeniach statyczno-wytrzymałościowych. Może być również podstawą dokładnych wizualizacji i rekonstrukcji wirtualnych obiektu. [1]. Przykładem zastosowania skaningu są działania diagnostyczne prowadzone przez Zespół Budownictwa Ogólnego i Zrównoważonego Rozwoju Politechniki Warszawskiej, we współpracy z Uniwersytetem Warszawskim, na wykopaliskach w Aleksandrii w Egipcie i w Tanais pod Rostowem w Rosji. W Na Kom-el-Dikka w Aleksandrii znajdują się późno antyczne (z IV w. n.e.) budowle podziemne, będące zespołem podłużnych, wzajemnie ortogonalnych korytarzy, wykonanych z ciosów wapiennych w kształcie klińców, przekrytych sklepieniem beczkowym. W miejscach krzyżowania się korytarzy sklepienie beczkowe przechodzi w sklepienie krzyżowe (Rys. 1). Jest to układ wyjątkowy i oryginalny, niestosowany powszechnie w późnym antyku. Skaning laserowy dał możliwość dokładnej identyfikacji kształtu korytarzy, technologii ich wykonania, elementów murowych, ich stanu technicznego, powstałych uszkodzeń, rys, wyboczeń i krzywizn. Otrzymane wyniki, wraz z badaniami laboratoryjnymi określającymi parametry fizyczne i wytrzymałościowe elementów murowych i zaprawy oraz obliczeniami statyczno-wytrzymałościowymi, dają możliwość dokładnego przygotowania programu zabezpieczającego, konserwatorskiego i rekonstrukcji antycznych budowli podziemnych. W Tanais pod Rostowem w Rosji znajdują się pozostałości miasta powstałego w III w p.n.e., należącego do Królestwa Bosporu Kimmeryjskiego. Badane skanerem laserowym 3d fragmenty konstrukcji są murami dzikimi, o różnym przeznaczeniu, wykonanymi na zaprawie wapiennej. [2]. W strukturze muru można wyodrębnić większe kamienie stanowiące obudowę muru i drobne kamienie, będące jego wypełnieniem. Wykonane badania makroskopowe i inwentaryzacja geometryczna w postaci skaningu laserowego 3D oraz dokumentacji fotograficznej i fotogrametrycznej stanowią pierwszy etap badania tych konstrukcji. Stanowią one podstawę do dogłębnej analizy stanu technicznego konstrukcji i programu konserwatorskiego. Kolejnym krokiem będzie ochrona uszkodzonych fragmentów ścian i konserwacja, w tym reprofilacja i wzmocnienie ścian za pomocą techniki anastylozy, opartej na autorskiej metodzie używanej wcześniej przez autorów i zweryfikowanej w misjach konserwatorskich prowadzonych w Tyritake, Krym, Ukraina, 2011-2013 [3,4].

Rys 1. Obraz przekroju wykopu otrzymany za pomocną skaningu laserowego

WNIOSKI

Diagnostyka starożytnych obiektów zabytkowych wymaga dokładnej inwentaryzacji konstrukcji wraz z identyfikacją ustroju nośnego. Szczególnie istotne jest stworzenie dokładnej inwentaryzacji rys, uszkodzeń i odkształceń elementów tworzących ustrój nośny. Specyfiką obiektów starożytnych, będących częścią wykopalisk archeologicznych, jest okresowy dostęp i możliwość prowadzenia badań i pomiarów, co utrudnia weryfikacje wyników. W tego typu przypadkach koniecznie jest wykonanie dokumentacji, która będzie możliwa do zweryfikowania bez dostępu do badanego obiektu. Wyjątkowo przydatnym narzędziem do tego typu zadań staje się, coraz częściej, skaning laserowy, który umożliwia szczegółową analizę kształtu badanych obiektów budowlanych oraz pomiary odkształceń i uszkodzeń sprzed ekranu monitora. Wyniki skaningu laserowego dają również podstawę do szybkiego i bardzo dokładnego sporządzenia modeli numerycznych, które mogą być podstawą dalszych analiz statyczno-wytrzymałościowych.

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