Towards objective visual documentation of cultural heritage artefacts. Seventeen years of the development of digital measurement techniques at Wilanów

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Museum of King Jan III's Palace at Wilanów

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How did it happen that an intensive development of digital documentation techniques began precisely at the Museum of King Jan III's Palace at Wilanów? The impulse to start it was the interdisciplinary research conducted since 2003, the purpose of which was to prepare a long-term program for the multifaceted conservation of the entire palace and park complex. During the exhaustive works, art historians, conservators and archaeologists repeatedly encountered situations where the analogue documentation techniques used so far proved insufficient. Being aware of the rapid development of digital techniques, we looked hopefully in their direction, searching for new documentation potential. We conducted this search initially through cooperation with external entities, and later, as we gained knowledge and experience, we ourselves began to define specific research problems and look for technological solutions that could meet these challenges. It turned out that many solutions, although technologically achievable, had not yet been developed; with the support of the Museum's management and thanks to a lucky coincidence that brought together a group of like-minded individuals, this resulted in a development and research activity that lasted several years.

When dealing with a process, it is difficult to determine where exactly it has begun. Nor do activities that are carried out consistently over a dozen years usually have a single cause. In trying to reconstruct how it all started, I think it is necessary to point to the confluence of several events that took place in 2006.[1] On 28 March of that year, Wilanów hosted a conference entitled 'Zapis obrazu, obraz zapisu' [A Record of an Image, an Image of a Record]. Various digital documentation techniques were presented, and one of the speakers was Dr. Robert Sitnik,

1 This does not mean, of course, that the journey of the Museum of King Jan III's Palace in Wilanów towards digitisation of resources began only in 2006. Ewa Jakubowska-Smagieł relates: 'The first digital photo to be taken by the museum staff dates from July 2000, taken by Waldemar Markiewicz, the then head of the Department of Scientific Documentation' (E. Jakubowska, 'Historia cyfryzacji w muzeum w Dziale Dokumentacji i Cyfryzacji' , p. 1). As in many other cultural institutions worldwide, the first steps on the path towards digital recording methods were related to the use of digital cameras and planar scanners, which were rapidly developing in the first decade of the twenty-first century. Treated initially as a technological novelty, digital cameras were used to archive ephemeral moments in the life of the museum and its surroundings, such as exhibition openings, reports, photographs of landscape or architectural elements. Gradually, with increasing confidence in the quality of digital reproduction (especially in terms of colour), digital cameras began to be used to create documentation of paintings, ceramics and other movable objects; in our Museum, this occurred around 2005.

who discussed the possibilities offered by structured light scanning. The presented documentation potential looked to me like an opportunity to solve the problem with fixing the inscriptions covering the surface of the Raszyn Battle Monument. Working in the Museum's Conservation Department at the time, I was preparing a conservation program for this extremely interesting object, located on the island behind the Roman Bridge in Wilanów. Erected in 1821, the monument consisted of a brick shaft covered with sandstone slabs. Dozens of inscriptions were carved on these slabs by various visitors to the site, the oldest of them dating from the mid-nineteenth century. On the one hand, these inscription tarnished the surface of the monument; on the other, they conveyed emotions from the monument's nearly two-hundred-year history. During the conservation process, we decided to remove them; however, we were keen to preserve the knowledge of them for future generations. Photographic documentation only partially answered the difficult mission. We expected much better results from three-dimensional documentation; and so, the measurements taken in the summer of 2006, at night, were the first attempt to use the technique of structure-light scanning in Wilanów. The team from the Warsaw University of Technology, led by Robert Sitnik, was very interested in performing these tests, as this presented one of their first opportunities to work 'in the field'. Of course, from the very beginning we encountered numerous surprises, which were later to always accompany the projects we carried out, because, after all, every object in the Museum is different and one can never be sure whether a solution that worked in one case would work in another. Then it turned out that the combustion generator powering our measurement system was generating vibrations that carried over to the measurement. The measurements had to be taken at night in order to obtain adequate contrast when projecting the stripes; this, however, lured masses of insects to us, many of which were captured on the scans taken at the time. At this point we realised that if we were to ever again perform measurements in the park using structured lighting, it would be advisable to enclose the measured object with a tent.

Every action we performed immediately generated issues of which we had not been aware beforehand. The object of further tests performed in cooperation with the Warsaw University of Technology were the measurements of the fireplace located in the South Gallery on the second floor of the Palace (Fig. 1). There, we had no problem with electricity or insects, but we did not know what spatial resolutions should be applied while taking the measurements in order to capture the information of interest in the scan. In the case of the fireplace, which consists of sandstone elements surrounding the hearth and plaster set pieces, we were concerned with documenting the method of making the various elements and capturing traces of the tools used in its making. The scanner

used by the Warsaw University of Technology was a prototype device constructed at the Department of Mechatronics and we were able to recalibrate it almost freely, which allowed us to perform preliminary tests with different measurement sampling density. In 2007, during further cooperation carried out within the framework of statutory activities, we made measurements of over a dozen engraved gems; this was occasioned by the making of the exhibition 'L'antica maniera. Zeichnungen und Gemmen des Giovanni Calandrelli in der Antikensammlung Berlin' [L'antica maniera. Drawings and Cameos by Giovanni Calandrelli in the Antikensammlung in Berlin], organised in cooperation with the Staatliche Museen zu Berlin.[2] The objects loaned from Berlin at the time were ideal for our purposes. We had plaster casts of small bas-reliefs, each only a few centimetres high, decorated with beautiful, very fine engravings. At the time, we were able to take measurements with a measurement sampling density of 1100 points per mm^2, which no one but us was yet using at the time. We tried to share the experience we gained internationally. With the results of the measurements already worked out, I strove to obtain information on what measurement accuracies were recommended in other countries. It soon became clear that there were no such arrangements, and the only answer I received was 'the more points the better',[3] which of course was no answer at all. At this point we realised that determining the desired precision of measurement would be our first goal. To accomplish this task, simple collaborative efforts between the Museum and the university were not enough; we needed a dedicated research project. We set about writing the first joint proposal between the Museum and the Department of Mechatronics in late 2008, and submitted it to the VI Development Project Competition of the Ministry of Science and Higher Education. We were very lucky, because the research project entitled 'Realisation of the idea of preventive conservation by means of precise 3D

Fig. 1

A three-dimensional model of the fireplace in the South Gallery of the Wilanów Palace, made on the basis of measurements taken in 2007

2 Author of the concept: Dr. Gertrud Platz SMB, curator: Eryk Bunsch; opened on 27 April 2007.

3 It concerned the resolution of the cloud of points resulting from the measurement. In most three-dimensional measurement techniques, the measurement sampling density (MSD) is given in the minimum number of measurement points obtained on the surface of the measured object per mm or square cm.

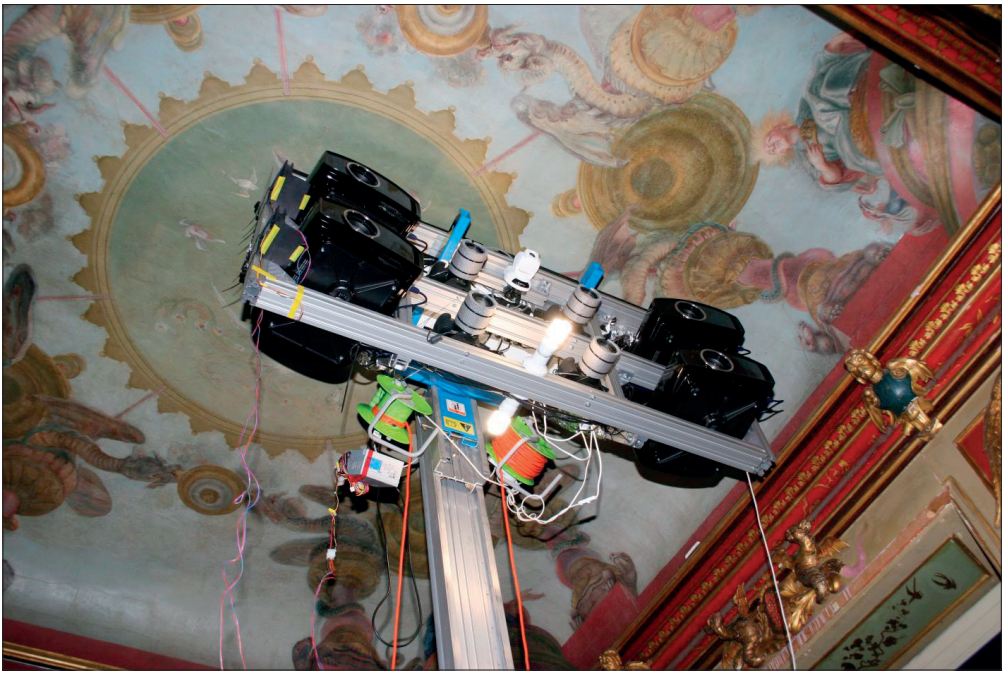

Fig. 2

The first version of the measurement head for scanning the interior of the Palace, designed and built in cooperation between the Museum and the Warsaw University of Technology. The King's Chinese Cabinet: taking measurements before the start of conservation works in the room, Wilanów 2011

documentation' received funding on the first attempt in 2009 and was then implemented until August 2012.[4]

The research conducted at that time resulted in findings which we are still following today.

At the time, the Museum collaborated with the Warsaw University of Technology on a project entitled 'Automated system for three-dimensional digitization of objects of Polish and European cultural heritage'. After the first tests at the Department of Mechatronics, the measuring station, in whose construction the industrial robotic arm was used for the first time, was transported to Wilanów and installed in a laboratory organized on the second floor of the Palace's north tower.

The very location of the studio shows the determination with which we carried out our research. The views from the tower were beautiful, while the atelier could only be accessed through a historic spiral staircase with sixty-three steps. In addition, the floor of the first-floor room had very limited load-bearing capacity, and when closed vigorously, the heavy oak doors on the first floor transferred the resulting vibrations to our measurements. There was no other vacant space for a studio, and we were delighted that, with every square metre of museum space being put to use, we got any space at all. After the launch of the N R17 project, we were able, with the support of the Museum management, to obtain

4 Research project N R17 0004 06/2009, entitled 'Zastosowanie precyzyjnej dokumentacji 3D obiektów zabytkowych w urzeczywistnieniu idei konserwacji prewencyjnej / Realisation of the idea of preventive conservation by means of precise 3D documentation'.

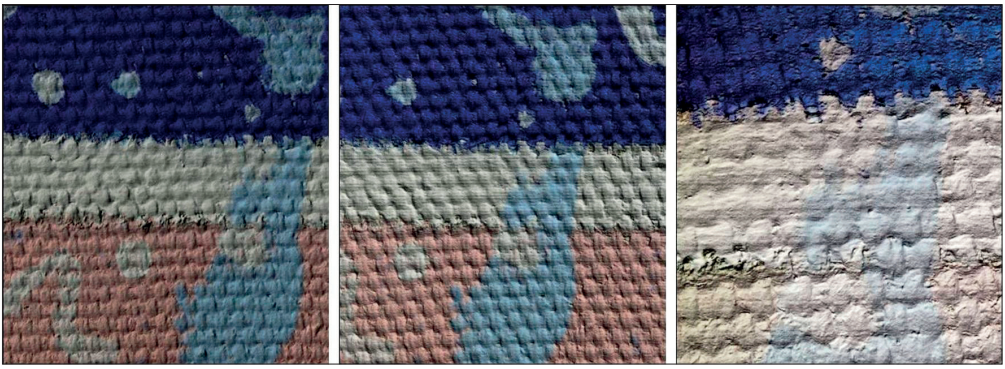

Fig. 3

A visualisation of the model in the form of a dense cloud of points, showing a copy of a fragment of the image of D. Hockney shown at three different measurement sampling densities of 1100 points per mm^2, 2500 points per mm^2, and 10000 points per mm^2, respectively. Project N R17 0004 06, sample no. 28

yet another small room on the second floor of the north wing. There, at last, we had a solid masonry floor, which gave us the ability to take measurements with much higher spatial resolutions. From then on, in the tower room we carried out tasks related to the automation of measurement and the use of a robotic arm, and in the new room we made test measurements of 52 material samples prepared in cooperation with art conservators. These technological samples, measuring 10 cm by 10 cm or 12 cm by 12 cm, were prepared so as to duplicate the typical surface characteristics of most cultural heritage objects.[5] Each was measured at three different measurement sampling densities of 1100 points per mm^2, 2500 points per mm^2, and 10000 points per mm^2 (hence the distances between adjacent measurement points in the cloud were 30 µm, 20 µm and 10 µm respectively) (Fig. 3). The results of the measurements in the form of dense clouds of points[6] were evaluated by art conservators, art historians and archaeologists to answer further questions. First of all, we tried to determine in which of the scans a specialist would be able to observe those stylistic and workshop features of the object that allow him to make a preliminary assessment of the workmanship technique and state of preservation of the object in question. For most of the samples, a result corresponding to the measurement sampling density of 2500 points per mm^2 was indicated.

5 Fifteen samples included tiles made in series of three from five natural stone types: granite, crystalline marble, compacted limestone, sandstone and porous limestone. Another twelve were samples of four wood types: two hardwoods (oak *Quercus robur* and linden *Tilia cordata*) and two coniferous woods (fir *Abies alba* and pine *Pinus sylvestris*). Thirteen samples were also prepared to mimic common painting techniques and the final group of twelve samples imitated various graphic techniques.

6 The Mechatronics Department then developed a special visualiser, 3DMassive (whose creator was Jakub Michoński), which allows models to be viewed as even very dense point clouds with color mapping and the ability to change the lighting conditions. This program is still used in Wilanów today due to the fact that it permits the visualisation of very large data sets while the degree of approximation and previewing successive layers of points are being chosen. Its disadvantages are that it cannot be made available on the Internet and that it requires a powerful workstation due to the amount of data it processes.

Determining the reference measurement resolutions was very important because of the need to plan the scanning process in such a way that it would gather the amount of data needed to create a digital product with the required mapping quality, but without creating redundant data. Taking measurements at measurement sampling density higher than required unnecessarily complicates the measurement, inflates the cost of the task, and produces redundant data which must then be stored.

In 2007, at the 'Digital Encounters with Monuments' conference organised by the University of Wrocław, Dr. Robert Sitnik and I became acquainted with the postulates of the London Charter presented by Anna Bentkowska-Kafel of King's College London, and we concluded that we needed to incorporate these recommendations into the path we were developing.

In 2011, in an interview with the *Computerworld Polska* magazine, Dr. Robert Sitnik and myself claimed: 'If […] we want to create conservation documentation, or determine the state of preservation of an object and its needs, more advanced technology is necessary. Only scanning with a resolution close to 10000 points per square mm allows us to meet documentation requirements'.[7] We said this because we had just completed a research project in which this spatial resolution was the highest we had tested and we assumed that only such resolution would meet all the requirements we had set for it. Soon after the project had been completed, however, we discovered that the resolution requirements for most objects did not need to be that high.

In the same year, 2011, when asked by a journalist from the *Przekrój* magazine whether 'digitisation of collections was a fad, a necessity or an opportunity for museums', I answered: 'I do indeed encounter views that digitisation can wait. Or the fear that digital data are less durable than those recorded on paper, that a virus would appear and destroy them. It is not so. It would be difficult to be a modern institution today and not have a digital record of your collections'. In the same article, describing our research priorities, I pointed out: 'For several years, in cooperation with a team from the Department of Mechatronics at the Warsaw University of Technology, we have been working on eliminating the human being from the measurement process and replacing it with an industrial robot. […] data processing is a tedious and time-consuming process. Human involvement increases the risk of error'.[8]

Sometimes we could count on media interest, as in 2011, when we assembled a 40-square-metre tent equipped with air conditioners in the Wilanów gardens, which we then moved around the lower terrace of the

7 D. Konowrocka, 'Skanowanie form przestrzennych', *Computerworld Polska*, no. 34/950, 2011, p. 21.

8 J. Tomczuk, '3D przyjacielem muzeów', *Przekrój*, no. 42 (3460), 2011, p. 30.

Fig. 4

Tent on the lower terrace of the park, Wilanów 2011

Fig. 5

Inside the tent, Wojciech Zaluski of the Warsaw University of Technology team operates a robotic measurement system while performing a scan in structured light on the surface of a sandstone vase

park, placing it one by one over each of the four sandstone vases. *Życie Warszawy* wrote: 'In the garden of the Wilanów Museum there stood a tent. Inside, in the semi-darkness, a powerful robot is scanning a large sandstone vase with extreme precision. This is part of a unique project carried out in cooperation with scientists from the Warsaw University of Technology' (Fig. 4 and Fig. 5).[9]

In 2011–2012, carried by a strong wave of media interest, we tried to create a vision of documentation as we believed we were to deliver within a few years. At the same time, we tried to define the scopes of application ourselves, as well to inspire others to further develop this vision. These actions gave birth to incredibly fresh ideas and opened up entirely new research perspectives, but also caused many disappointments when we were stopped by technical problems that piled up or when we were unable to satisfy the users' excessive expectations. Some of those users

9 J. Gajda-Zadworna, 'Trzeci wymiar zabytków', *Życie Warszawy*, no. 178, 2011, p. 7.

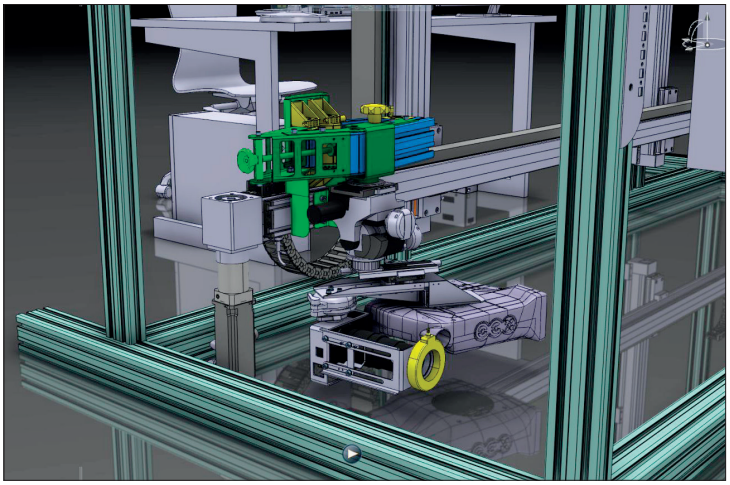

Fig. 6

Design for the Station for Automated Painting Measurement (SAPO) created in cooperation with Warsaw University of Technology as part of the WPR Kultura+ project

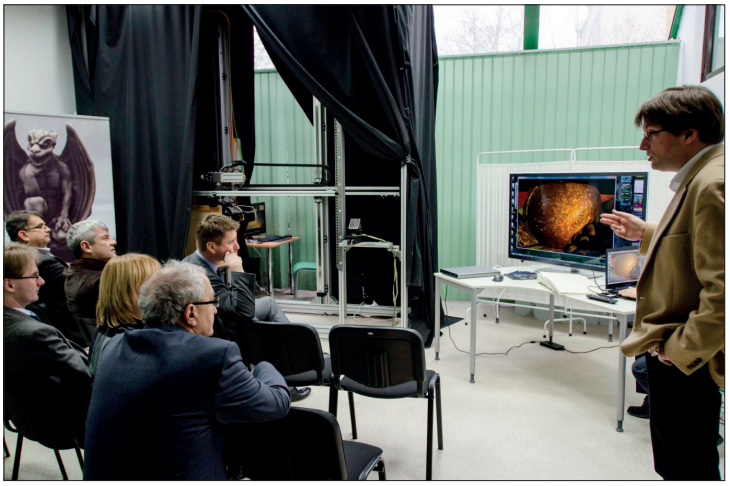

Fig. 7

Presentation of a prototype of a station for automatic scanning of canvas painting surfaces with measurement sampling density of up to 10000 points per mm^2. Seated in the audience are (left to right): Piotr Majewski (then director of NIMOZ), Waldemar Markiewicz (then head of the Documentation and Digitisation Department of the Museum of King Jan III's Palace at Wilanów), Paweł Jaskanis (Director of the Museum of King Jan III's Palace at Wilanów) and Jarosław Czuba (then Deputy Director of NINA)

shared our undying optimism, while others became highly critical of the proposed solutions (Fig. 6 and Fig. 7). These experiences made me realise how incredibly important it was to be as precise as possible about the effect of the planned work.

We often had discussions with Dr. Sitnik about whether the visions we were creating were not too daring; whether perhaps we should define the various stages of technological development more simply, so that they would be easier to achieve. Then the argument invariably arose that if the vision was not bold enough, it would not interest anyone except a handful of technicians. We were therefore doomed to forever chasing ambitious promises. With the benefit of years of perspective, it can be said that throughout this time we have consistently pursued the goals we defined at the beginning of the journey. We were certainly over-optimistic when trying to estimate how long it would take us to achieve them. We went from an initial target of a few to a dozen years,

and even so, some of those goals, such as the full automation of measuring complex spatial shapes, are still waiting to be perfected and implemented. On the other hand, looking back, it also turned out that we were one of the few centres in the world that posed such questions at all and sought to find systemic answers to them.

In 2011, in the interview with *Życie Warszawy*, I declared that ultimately we wanted to 'develop standards for the digitisation of monuments, to set standards that, we hope, will be a Polish proposal in the European Union'.[10] Unfortunately, after thirteen years, the issue is still open, and the problem is becoming more pressing. Due to the current lack of opportunities for large-scale research projects in recent years, we have tried to develop at least small fragments of this problem, as evidenced by the work on determining the required precision of scanning for making copies of woodcarvings using CNC (Computerized Numerical Control) milling.[11]

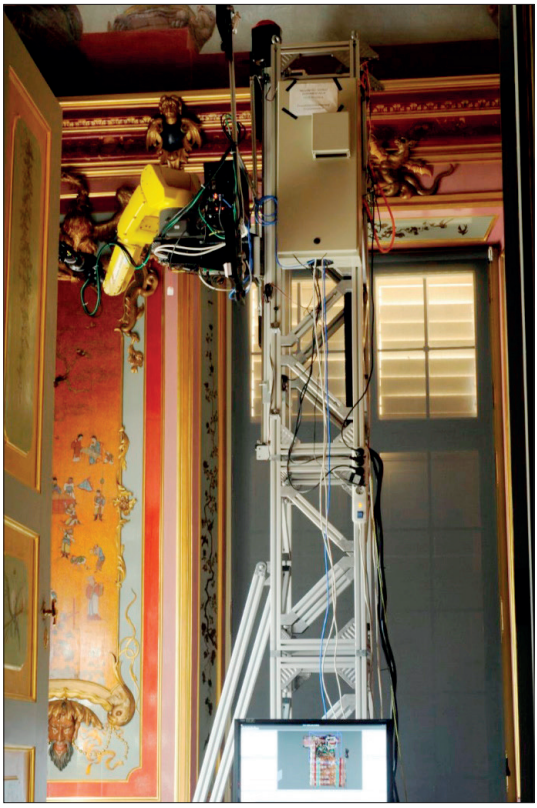

Fig. 8

The second version of the measurement head for scanning the Palace's interiors, designed and built in cooperation between the Wilanów Museum and Warsaw University of Technology. The King's Chinese Cabinet – measurements after the completion of conservation works in the room, Wilanów 2015

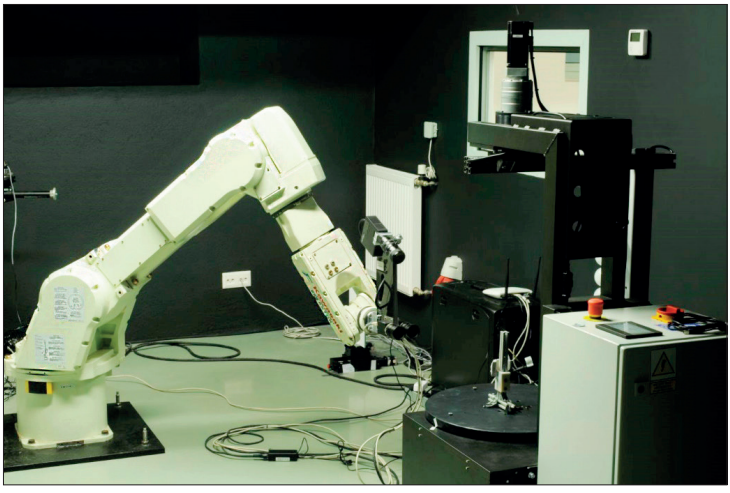

Fig. 9

Interior of the 'Laboratory for 3D Documentation' in the basement of the Orangery with the automated workstation with structured light scanning system, Wilanów 2016

10 Gajda-Zadworna, 'Trzeci wymiar', p. 7.

11 E. Bunsch, 'The possibilities of making copies of wooden historical objects by CNC milling based on digital three-dimensional models', Archiving 2023 Conference, Oslo.

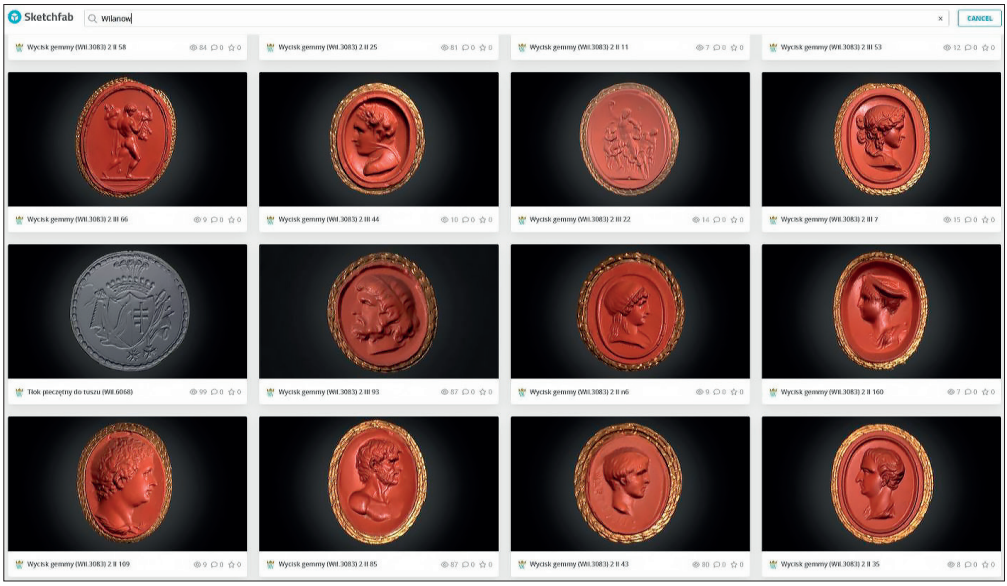

Fig. 10

The site of the Sketchfab platform, which published three-dimensional scans of engraved gems and stamp seals digitised as part of the www.museums project

We constantly hope that we will be able to continue our research on digital technologies in Wilanów and make our contribution to the development of standards of minimum quality requirements for the created digital documentation of cultural heritage objects. While waiting for such an opportunity, we are focusing on popularising the knowledge we have gained by, among others, implementing projects such as www.muzeach (Fig. 10),[12] in which we, as the Museum, were the leader of a consortium of five Polish museums carrying out a complex project involving the creation and sharing of digital documentation.

TIMELINE:

2000 – The first digital photo is taken at the Museum of King Jan III's Palace at Wilanów.

2003 – Digital measurement techniques are applied for the first time, in preparation for the revitalisation works at the park and palace complex.

2003 – Cooperation with the Laboratory of Interdisciplinary Research of the National Center for Research and Documentation of Monuments (KOBiDZ) is initiated. Orthophotographic documentation of the Palace's facade and of archaeological works in progress begins to be created, including with the use of a Cyrax 2500 laser scanner.

2005 – A geographic information system (GIS) begins to be created at the Museum. The development of this documentation based on ArcGIS software from ESRI has been ongoing since 2009 and it is being consistently implemented to this day.

12 www.muzeach is a project implemented within the framework of the Operational Program Digital Poland 2014–2020 (Grant Agreement no. POPC.02.03.02-00-0009).

2005 – The first attempts to create three-dimensional documentation of movable monuments are made by an external company DEPHOS using a Konik-Minolta Vi-9i scanner. The work results in models in the form of a grid of triangles with a texture overlay.

2007 – The Museum enters into cooperation with the Department of Mechatronics of the Warsaw University of Technology in making test measurements of three-dimensional engraved gems, occasioned by the making of the exhibition 'L'antica maniera. Zeichnungen und Gemmen des Giovanni Calandrelli in der Antikensammlung Berlin', organised in cooperation with the Staatliche Museen zu Berlin (author: Dr. Gertrud Platz SMB, curator: Eryk Bunsch, 27 April 2007). Measurements were then made with a measurement sampling density of 1100 points per mm^2.

15–16 October 2007 – The 'Digital Encounters with Monuments. Modern Methods of Collecting and Sharing Access to Knowledge on Monuments' Conference, organiser: Institute of Art History, University of Wrocław.

1 September 2009 – 31 August 2012 – Duration of the Research Project N R17 0004 06/2009 entitled 'Zastosowanie precyzyjnej dokumentacji 3D obiektów zabytkowych w urzeczywistnieniu idei konserwacji prewencyjnej / Realisation of the idea of preventive conservation by means of precise 3D documentation', 6th Competition of the Ministry of Science and Higher Education for development projects.

2009 – The project 'Automated system for three-dimensional digitization of objects of Polish and European cultural heritage' is carried out by the Warsaw University of Technology in cooperation with the Wilanów Museum.

1 July 2010 – A framework cooperation agreement is signed between the Faculty of Mechatronics of the Warsaw University of Technology and the Museum of King Jan III's Palace at Wilanów (then operating under the name the Wilanów Palace Museum). Robert Sitnik and Eryk Bunsch are appointed to coordinate joint activities in the field of 'research on monitoring shape changes over time' and 'research on automatic three-dimensional digitisation of museum artifacts for conservation and documentation purposes'.

26 October 2010 – A workshop 'Integrated system for 3D digitisation of cultural heritage objects with automatic processing and export of virtual models' is organised in the framework of the 'Research on 3D digitisation and reconstruction of European cultural heritage objects' project carried out in cooperation between the Institute of Micromechanics and Photonics of the Warsaw University of Technology and the Museum of King Jan III's Palace at Wilanów.

2010–2014 – The Multiannual Government Program 'WPR Kultura+' is a nationwide program with a total budget of 120 million PLN, operated by the National Audiovisual Institute (NInA). Projects submitted under the program by the Wilanów Museum receive funding four times.

2010 – 3D digitisation of a selected collection is carried out in the framework of POIiŚ (Operational Programs Infrastructure and Environment) project 'Revitalisation and digitisation of the eighteenth-century palace and garden complex in Wilanów'.

2011 – A group of experts begins work to develop preliminary digitisation recommendations, coordinated by the National Institute for Museology and the Protection of Heritage Collections (NIMOZ), coordinator: Anna Kuśmidrowicz-Król.

November 2011 – The cooperation is instituted between the Museum of King Jan III's Palace at Wilanów and the Museum of the Archdiocese of Warsaw, represented by its director Father Andrzej Przekaziński.

November 2011 – The works begin on the setting up of a new measurement laboratory in the basement of the Orangery; interdepartmental arrangements are made at the Museum.

2–5 September 2012 – The Eighteenth International Conference on Virtual Systems and Multimedia is held in Milan. E. Bunsch, A. Guzowska and R. Sitnik give a presentation '3D scanning of two different objects'.

2012–2016 – The Museum participates in the international COST (European Cooperation in Science and Technology) project TD1201, entitled 'Colour and Space in Cultural Heritage (COSCH)', coordinated by the University of Technology in Mainz (Germany).

2012 – The Laboratory for 3D Documentation is established at the Museum of King Jan III's Palace at Wilanów.

29–30 November 2012 – The 'New Media. The Virtual World and the Perception of Art' conference is organised by the Institute of Media Art of the Academy of Fine Arts in Warsaw. E. Bunsch gives a presentation 'Is aesthetic perception of virtual works possible? On the peculiarities of the perception of digital data'.

2014–2015 – The POIiŚ (Operational Programs Infrastructure and Environment) project 'Revitalization and digitalization of the only Baroque royal residence in Wilanów in Poland: Digitisation of two rooms, the King's Chinese Cabinet and the King's Wardrobe, with a measurement sampling density of 100 points per mm^2 (structured light scanning)' is carried out. A basement room in the Orangery is reconstructed and adapted for the Measurement Laboratory of the Laboratory for 3D Documentation.

2015 – An experimental multimodal measurement head (prototype) is created within the framework of the 'Wilanów Digital Museum + (IV stage)' project. It integrates the measurement of shape by scanning in structured light with the measurement of colour characteristics and the BRDF parameter (Bidirectional Reflectance Distribution Function, a function that determines how light is reflected and scattered) measured for each measurement point in the point cloud (with a measurement sampling density of scanning of 400 points per mm^2).

2017–2019 – The task ‘Three dimensional documentation of a selected collection of heritage objects’ is carried out within the framework of the ‘Restoration and preservation of the symbol of Polish cultural heritage – the Museum of King Jan III’s Palace at Wilanów’ project by the Department of Mechatronics of the Warsaw University of Technology. It includes

a) measurement by technique of structured light scanning of the Queen’s Antecabinet and the Al Fresco Cabinet with a measurement sampling density of 100 points per mm^2;
b) measurement of 12 ceramic sculptures by scanning in structured light scanning with a measurement sampling density of 2500 points per mm^2;
c) cyclic measurement (seven series of measurements taken in three seasons: spring, summer and autumn) of twelve locations on the Wilanów Palace’s façade (in 12 cm by 12 cm format with a measurement sampling density of 2500 points per mm^2).

2018–2023 – The Museum participates in the international project ‘CHANGE. Cultural Heritage Analysis for New Generations’ carried out within the framework of the European Commission’s ‘Horizon 2020’ research and innovation program under the Marie Skłodowska-Curie Actions (Grant No. 813789) coordinated by NTNU (Norway).

6–7 November 2019 – The conference entitled ‘Revolution: Velvet × Digital. 30 Years of Digital and Social Media in Museums’ is organised by ICOM in Bratislava. E. Bunsch gives the presentation ‘To be or not to be – proper digital strategies for museums’.

2019–2022 – The ‘Operational Program Digital Poland’ and the www.museums program are implemented. This consortium program including documentation work is conducted in five museums, with the Museum of King Jan III’s Palace at Wilanów as the leader and coordinator of the project, responsible for proposing digital documentation paths and quality control.

17–18 November 2022 – The ‘Digitization in Museums. Discussion Forum on the Problems of Creating Digital Documentation’ is organised in Wilanow in cooperation with the National Institute for Museums (formerly National Institute for Museology and the Protection of Collections).

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