Karol Król • Józef Hernik

Digital Heritage
Reflection of Our Activities

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Foreword

Digital artifacts have a significant historical value which will only increase over time. Archived materials offer us an insight into the past, and cast a light on the origin of events. New regulations, techniques, tools, methods and procedures to increase the effectiveness and other types of values of institutional digital data archiving are still being sought with the aim to preserve and make available their greater volume. However, a unified institutional archiving system raises concerns over the conscious and targeted selection of data to be preserved. More options arise for free choice about what to target and preserve, and how. But more options also create greater possibilities for problems, even for evil-doing. A specific archival system behemoth could at some point turn into a tool of influence, and its decision-makers could “erase the past” or designate “only the right content” for archiving. All this raises the following questions: what deserves to be regarded as digital cultural heritage and, thus, to be preserved? Who is competent to decide what will be archived and based on what criteria? This study presents selected ways to preserve the collection of digital software, and examples of digital archives. It describes digitisation as a process that results in generating digital reproductions. It also focuses on disadvantages and advantages of digitisation, and emphasises the role of digital equivalents as objects resulting from one or more digitisation processes. The study demonstrates that digitisation supports the performance of tasks associated with the preservation, sharing and protection of cultural heritage objects, and enables the implementation of the concept of open archives that offer remote access to digital surrogates. Moreover, it presents selected practices about making cultural heritage objects available on the Internet, including examples of the use of selected design techniques and tools for interactive presentation of objects by means of visualisation and digital maps. The techniques and tools presented in the paper increase the availability and range of information on cultural heritage objects, and contribute to the effectiveness of their protection. In addition, this research notes some challenges that arise about various standards for digitizing cultural heritage objects.

Chapter 1

Cultural heritage

"Heritage" is a broad term that not only refers to research into material remains of human activities (as in archaeology) but also to immaterial concepts such as traditions, cultural evidence or narratives. As Rahaman and Beng-Kiang [2011] observed, it is a process of engagement rather than a condition; it is a medium of communication, a means of transmission of ideas and values and can be associated with types of knowledge that include the material, the intangible and the virtual [Graham 2002]. Heritage encompasses an ever-changing collection of objects and symbols, complexity of images, cultural artifacts, objects of historical value and a diverse range of ethnic customs which are of significance to local communities [Thwaites 2013]. Heritage is owned jointly by the society which has the right to use it in different ways and for different purposes (e.g. tourism) [Król 2019], but in such a way as not to deplete its resources or jeopardise its integrity [Pawleta 2016].

Cultural heritage is a set of components of culture which are regarded as valuable and worth passing on to subsequent generations [Dzięglewski and Juza 2013]. It is an individualised, dynamic discursive space within which a reservoir of cultural resources from the past and its associated meanings are constructed through interaction [Nieroba et al. 2009]. Cultural heritage bridges the gap between the past, the present and the future, maintains the continuity of a social group, and is the basis for identity in its individual and collective dimensions [Dzięglewski and Juza 2013].

The issue of how to engage in dissemination and popularisation of cultural heritage, including archaeological heritage, is linked to any proposal for shaping social awareness of the protection of cultural assets and, at the same time, natural assets that can sometimes be distinguished from some corresponding cultural assets. At this point, it is worth noting the need for linking cultural and natural heritage (Fig. 1) [Lewicki 2016]. This is supposed to stimulate and develop public awareness of various cultural heritage values, e.g., for the understanding of the past and the dangers posed to such understanding. Making cultural heritage accessible to the general public and the popularisation of knowledge in this field can if rightly arranged improve the basis for its protection [Pawleta 2016].

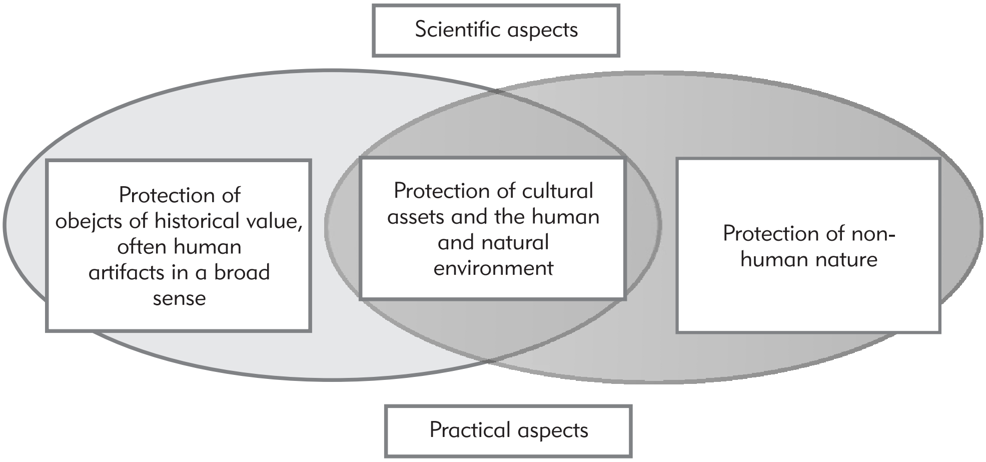

Fig. 1. Relationships existing between the protection of historical objects and the protection of nature

Source: Authors' own study based on Lewicki [2016]

The conceptual range of the expression "cultural heritage" is neither precise nor clearly understood. Cultural heritage, similarly to the associated concept of tradition, is often regarded as self-explanatory and requiring no explanation. Cultural heritage is considered equivalent to historical objects, cultural assets or cultural resources. Objects and phenomena to which these terms are applied are distinguished by the fact that they are carriers of certain values which can generally be called "cultural". A cultural asset is any movable or immovable object, old or contemporary, that is of significance to heritage and cultural development because of its historical, scientific or artistic value. Cultural heritage is the part of cultural assets that has been regarded as valuable by subsequent generations and, therefore, has survived (at least, to some extent) to the present day [Vecco 2010, Sankowski et al. 2016].

Cultural heritage comprises material and spiritual achievements of the previous generations as well as the achievements of our times. It also means a value, material or immaterial, passed on by the ancestors and characteristic of a particular culture; however, heritage can be perceived in different ways. The same item, object or content may be of value to some and be their heritage, while to others it may be something unknown or incomprehensible.

Cultural heritage is usually considered equivalent to historic objects or monuments understood in a traditional way as e.g. movable or immovable objects, sets of objects, locations or works of art. Therefore, it is the "historic monuments" that are provided with institutional care most frequently. These can be architectural structures or geographical locations in which historically significant events have taken place (Fig. 2). Such objects and sites are intuitively perceived as

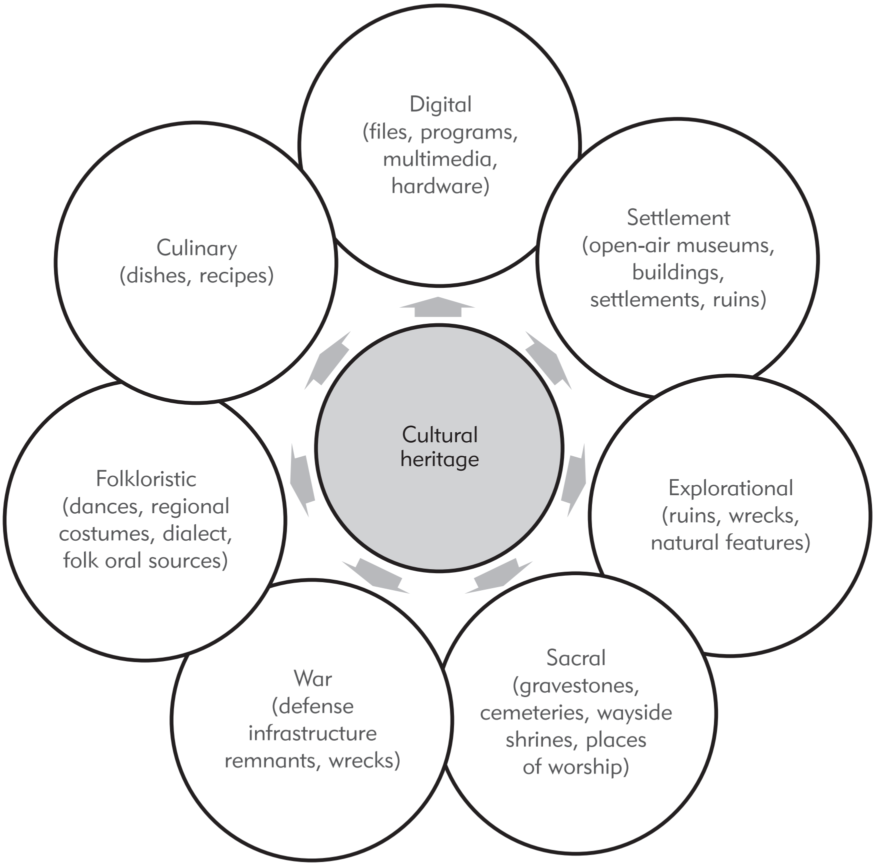

Fig. 2. Selected objects of cultural heritage

Source: Authors' own study

historically significant because they are a testimony of the bygone era or breakthrough events. The situation is slightly different when it comes to digital contents since they are part of more recent history. Cultural heritage, however, not only comprises historic buildings, traditional dishes, songs or clothing; it also includes computer programs, radio broadcasts, multimedia constructs and digital contents. In view of their impermanence, they may be in need of protection even more than other cultural assets [Garda 2014]. An example of this can be the oldest film material produced on nitrocellulose substrate. Such a substrate decomposes slowly and continuously, with the decomposition accelerating over time. First, the cinematographic film substrate turns yellow, then brown, and afterwards crumbles and becomes irreversibly degraded [Supraniuk 2019]. Similar phenomena of equipment damage due to chemical reactions affect complex devices such as computers or game consoles.

Cultural heritage is worth looking at from the angle of resources. When regarding cultural heritage as a resource, a unique instance of it is often limited, non-renewable and vulnerable. Moreover, it is often someone's property. Currently, a gradual shift can be observed from the concept of cultural heritage protection to reasonable heritage management, in line with the assumptions of the sustainable development concept (Fig. 3).

On the one hand, it is indicated that heritage is an object of protection, while on the other its potential, that should be used for social and economic development, is emphasised. The concept of reasonable management of this heritage involves using it in such a way so as to obtain the greatest possible benefit for present generations while maintaining its ability to satisfy the needs of future generations. To put it in another way, cultural heritage management involves decisions about what will be preserved, and how it will be used now and in the future [Pawleta 2016]. Heritage is therefore a source of value for a specific community that is at the same time obliged to manage the resources entrusted to it. This is also true for digital resources.

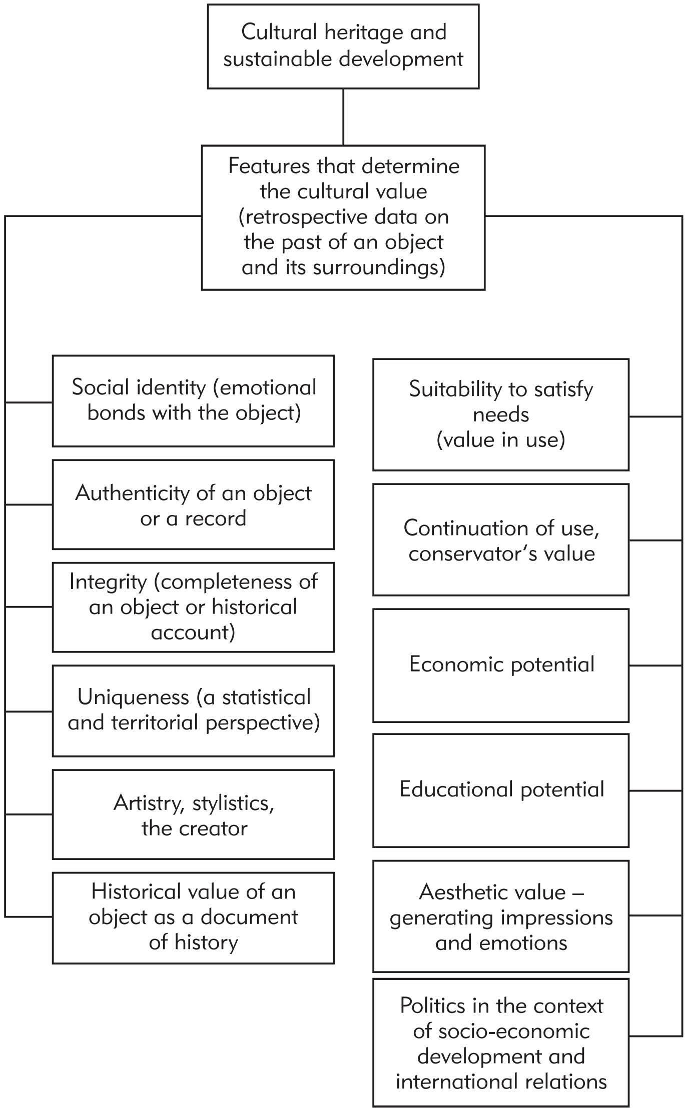

Fig. 3. Cultural heritage and sustainable development

Source: Authors' own study

Chapter 2

Digital cultural heritage

The number of digital heritage objects has been growing rapidly since the 1990's when computers became more accessible and cheap enough to be commonly used [Dave 1998]. It is referred to differently, for example as virtual heritage defined as the use of technology to interpret, protect and preserve natural, cultural and global heritage [Stone and Ojika 2000], or virtual culture, e-culture, e-heritage, new heritage or digital history [Smith 2006, Thwaites 2013]. UNESCO [2003], in their Charter for the Preservation of Digital Heritage, has defined digital heritage as the "cultural, educational, scientific and administrative resources, as well as technical, medical and other kinds of information created digitally, or converted into digital form from existing analogue resources" and includes "texts, databases, still and moving images, audio, graphics, software and web pages". Digital heritage can be considered to comprise facts and information (architectural plans, digital ortho-images, 3D models, scans of heritage artifacts or sites, photos of locations, etc.), fiction, interpretations or "best guess" (digital proxy, re-creations or transformations of landscapes, people, building adornments etc.) and fantasy in varying forms and degrees with interpretive narratives of the past [Thwaites 2013].

Digital heritage comprises three main areas: (1) documentation, (2) presentation and (3) dissemination, and one of their main objectives is to promote the knowledge of history and culture [Tost and Champion 2007]. Due to the accessibility of digital representations of cultural heritage objects, interest in cultural heritage has increased worldwide. Digital surrogates provide access to valuable, rare and fragile artifacts. Projects related to digital heritage raise the global community's awareness, encourage virtual and even physically enacted tourism, and provide means of recording, protection, interpretation and education, thus fostering universal intercultural communication [Thwaites 2013].

Digital heritage objects can be "digital by nature" i.e., "born digital" e.g. electronic periodicals or original multimedia contents (Fig. 4), or can take on the form of a "digital surrogate" (produced on the basis of analogue originals e.g. 3D visualisations or graphic reproductions [Rahaman and Beng-Kiang 2011]. Digital heritage is created in many different formats. What is now of increasing importance are the totally "born digital" projects, those that are completely computer generated and presented with no analogue equivalent [Kwiatek and Woolner 2010, Ch'ng and Stone 2006].

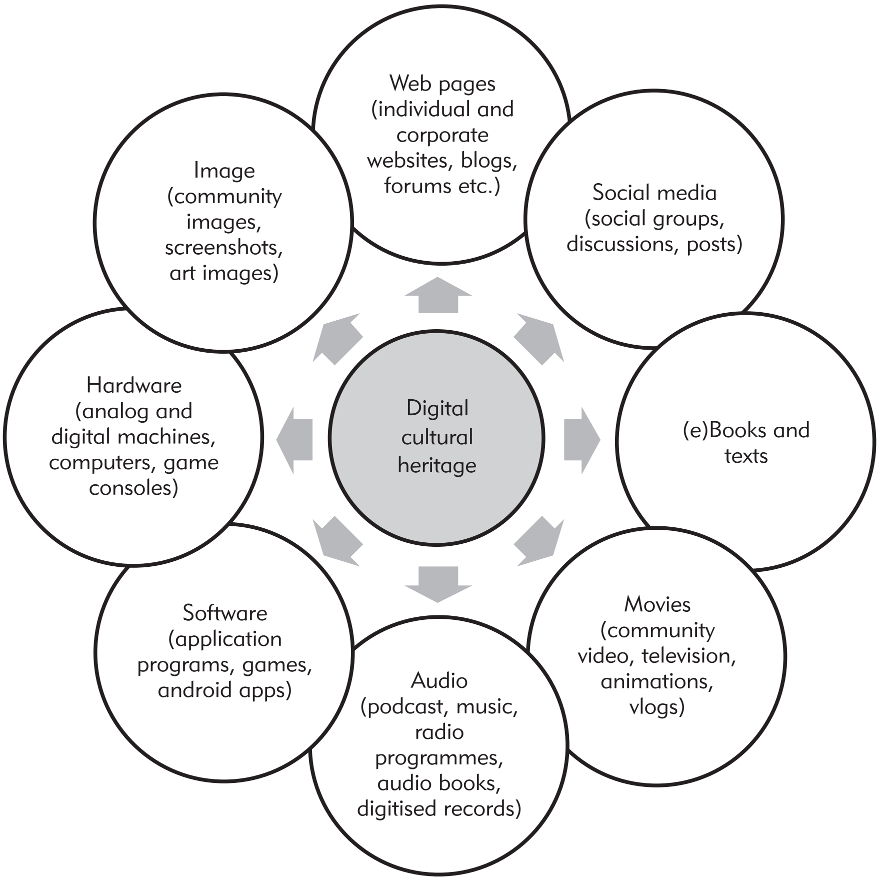

Fig. 4. Examples of digital cultural heritage objects

Source: Authors' own study

The concept of smart heritage and cultural futures refers to applications that combine imagery and sound captured at locations of high cultural significance with animation, narratives and immersive sound and vision technologies to create hybrid virtual-real worlds rich in detail [Kenderdine and Shaw 2009, Thwaites 2013]. Thwaites [2013] referred to smart heritage projects as "mobilised digital heritage" because it has been designed with various cultures, environments and audiences in mind. Moreover, Thwaites noted that much of the future of digital heritage re-presentations lies in what Balsamo [2011] describes as "public interactives", "a category of exhibits that use interactive technologies to present content to a wide range of public audiences".

Digital contents are inherently "unstable" i.e. easy to replicate, modify and delete. Moreover, they are subject to technical ageing and physical decomposition (bit rot [Odersky and Moors 2009, Król and Zdonek 2019]), which means that they have no "cultural future". At the same time, they have a permanent value and significance, and are dependent on computers and associated tools, with hardware and software undergoing constant changes. Therefore, by nature digital contents are determined by memory carriers and format updates. All these features need to be taken into account when creating digital objects, if they are supposed to be perceived as "intelligent heritage" that will be transferred to the "cultural future" [Thwaites 2013].

2.1. The problem of data loss

Many researchers point out that digital heritage objects disappear faster than material heritage which takes on the form of historical, physical objects [Koller et al. 2009, Cohen and Rosenzweig 2006, Kuny 1998]. Thwaites [2013] called this phenomenon "The Vanishing Virtual" or "Disappearing Digital". Mostly it is happening due to inappropriate standards, a lack of understanding and in some cases just a rush to capture, and digitize, in order to "save" it before it is gone, often resulting in the opposite result [Thwaites 2013].

The loss of data, most of which are recorded in a digital format, has become a civilisational problem. Data recorded on a magnetic tape or floppy disk may not be readable at present. Not only the disks themselves but also programs, operating systems and recording devices have gone out of use. Files recorded on archaic data carriers may remain intact, but the access to them is difficult or even impossible. Soon, it will be possible to treat many of these files as if they have never happened. For subsequent generations, they can be an artifact from the past. The scale of the phenomenon is shown by the example of a "sample" of irreversibly lost digital collections from the last 50 years. 50 per cent (approximately 25,000) films produced in the 1940's, most of television interviews, the first-ever e-mail sent in 1964, and many more objects of intellectual and cultural heritage are unavailable now [Chen 2001].

Digital data storage is relatively easy; however, ensuring their availability and usability is no longer like that [Brand 1999]. Reverse engineering, hardware and software emulators as well as other mechanisms may be used to “resurrect withdrawn files” whose format is not supported anymore [Cerf 2011]. Allison M. Hudgins [2011] asked the question: will historians in the future have an opportunity to analyse programs and various digital contents from the past that have had a significant (cultural) impact on the society at the turn of century? If no significant conservation measures are taken, they may disappear irretrievably and more quickly than it may seem [Lee 2018].

Pierre Nora, when writing about the “acceleration of history”, pointed out that what is experienced as the increasingly rapid transformation of the present into the historical past only reinforces the common belief that everything created by the past can disappear. This provides an impetus for the virtually obsessive creation of archives in order to “completely preserve the present and to absolutely save the past”, since the fear of instant and ultimate disappearance is combined with anxiety about the sense of the present as well as anxiety as to whether the future will provide a slightest evidence of it, a faintest trace (...) [Nora 1989]. Many years ago, Nora predicted the end of spontaneous memory that has taken refuge in gestures and customs, in the skills passed on by unwritten traditions, in knowledge, natural reflexes and deeply rooted recollections. He observed the birth of memory that the described as “modern memory” or archival memory, based “on the materiality of traces, innumerable data, image visibility”, whose “vocation” is to record everything, and which shifted the responsibility for remembering onto an archive [Karpińska 2014]. On the other hand, all preserved information, from paintings on cave walls to clay tablets and video-recorded speeches, have a value even if it is only momentary [Smith 2002].

Not everything that has been created in the digital form and originates from the past is automatically heritage. Striving to convert “everything” into the digital form is inappropriate, even if it were possible. The real challenge is to make analogue materials more accessible thanks to the possibilities offered by the digital technology [Smith 2002]. Not all data are valuable, and not all of them need to be preserved [Weiner 2016]: “Let us not archive everything. This, after all, has never been practiced; it is, however, necessary to preserve a wide range of digital artifacts of everyday life, even if they are “silly”. (...) We should preserve and archive certain cat videos, since they are part of our culture. Yet, we should not save millions of cat videos.” Paradoxically, it is the digital nature of today’s world that allows archivists to document the complexity of things to an extent that was never possible to reach before [Mottl 2015].

There are many initiatives aimed at preserving as many digital artifacts as possible. It is sufficient to mention the measures taken by the Institute of Museum and Library Services (IMLS), the National Endowment for the Humanities (NEH), the National Science Foundation (NSF), the Internet Archive or the National Digital Archives in Poland. Although the problem is worrying, it is sometimes exaggerated. In Bertram Lyons' opinion [2016], the issue of digital heritage preservation is often presented as if only few people are involved in data archiving. However, archives are built and maintained by numerous entities, from NASA to the Smithsonian Institution, from Harvard to Indiana University, from the Internet Archive to the British Library. The very list of projects and studies dedicated to the preservation of digital heritage is sufficiently long to fill an archive, not to mention the considerable volume of digital resources collected and processed on a daily basis by archivists, librarians, museum staff and many other people worldwide.

2.2. Digital dark age

The term "digital dark age" is most often mentioned in the context of digital resource preservation (archiving). We are living in the midst of a digital dark ages because enormous amounts of digital information are already lost forever [Kuny 1998]. Digital dark age is an enormous void filled with a myth and speculation – digital darkness poses the risk of interpreting the past without documentary evidence. Information in the digital form i.e. much evidence of the world we live in is more fragile than papyrus fragments buried with pharaohs [Conway 1996]. Elimination of access to data is most frequently due to their removal (deletion), creation in one of the unsupported formats, or physical damage to a data carrier. Many datasets are obsolete, which is largely due to technological changes. Many technologies and devices become obsolete when their suppliers provide new products, often without backward compatibility, or when companies cease their operations. There are many document formats and numerous types of data carriers, each of which can have its own hardware and software dependencies. If the hardware and software necessary to read particular files are not available, the information recorded in the files will be lost. In addition, due to the increasingly restrictive regulations concerning intellectual property and licensing, many digital resources will never be placed in library collections to be archived.

Digital dark age looks a bit differently from the archivists' point of view. Rodney Carter [2004] offered an insight into the paradox of large (State) institutions' determination to ensure the continuity of archive-keeping and the completeness of archives. At the same time, the same institutions object to their activities being fully documented. Tansey [2016] pointed out that State registers may be, and often are tampered with or destroyed in order to protect "the powerful (mighty) of this world". For this reason, the State (institutional) records should not be the only evidence (data source). And what happens when the things sent to archives are only a remnant of *public relations*? What can archivists, documentation managers and other archive employees do in order to increase the completeness and authenticity of institutional records? These questions remain open.

Not all materials are lost due to having been destroyed. Many archivists have limited capacity to process and preserve materials, mostly due to a chronic lack of manpower and resources. A report of 2014 indicated that approximately 33,000 boxes with documents to be transferred to the British Columbia Archives had been stored instead of archived. According to the OIG (Office of the Inspector General) report, 28% of textual resources of the National Archives and Records Administration have not been processed yet [Tansey 2016]. In the light of staff shortages and underfunding as well as the lack of possibility for archivists to access the entirety of the data, the "blank spots" in archives may increase. Moreover, archiving is not made any easier by the increasing volume of data as well as their diversity and complexity [Newman 2012a]. Therefore, the spectre of digital dark ages seems to take shape. However, the digital dark age is not going to occur in the way portrayed by the media. Priority actions should not be overshadowed by fear of being unable to ensure availability and durability of (all) the generated information.

Chapter 3

Preservation of digital contents

Preservation of digital data implies the maintenance of stored information – catalogued, accessible and usable – on data carriers. This requires a lot of expenditures, but the information generated on an ongoing basis and up-to-date has an economic value. As regards archives, the situation is slightly different. It is difficult to find business reasons for their expansion and maintenance. Creators or collectors of digital information rarely have sufficient motivation or skills, or enough perseverance to store all digital materials. This is a long-term task, usually tackled by non-profit organisations, libraries and universities. The increasing complexity of digital artifacts is not facilitating this.

The preservation of (computer) programs is often incomplete. Currently, libraries and national archives have no consistent data collection strategies. What is more, their aim is not to preserve the access to and functionalities of the runtime environment i.e. software and hardware. This is conducive to archiving which is carried out "bottom-up" [Tait et al. 2013]. Archaic hardware and software are kept by home users of fan communities, all of this resulting from avocational and sentimental attachment. Private collectors and fan community web pages serve an important role in providing access to archaic titles; however, these actions are often not methodical and systematic, leaving aside the question of technical deficiencies and legal uncertainties [Pinchbeck et al. 2009].

Software archiving is not easy. One of the problems is the physical deterioration of data carriers and format ageing. More serious challenges, however, arise from the lack of interest in archiving, increasing costs of archiving and restrictions resulting from copyright protection [Hudgins 2011, Newman 2013, Lee

2018]. Brandt [1999] pointed out that the problem of digital data preservation appears to have neither a technical nor technological nature. There are techniques and tools available to prevent problems such as "bit rot". The problem lies in the lack of "digital culture" and habits that support data preservation.

Kuny [1998] indicated three main actions that could support the preservation of digital resources: the preservation of technology (hardware and software); technology emulation; and data migration (the transfer of data to newer, more durable, and more capacious data carriers). Moreover, a significant role in the preservation of cultural heritage objects is played by digitisation [Conway 2015].

3.1. Digitisation

In recent years, digitisation of various objects followed by the dissemination of their digital surrogates via the Internet has become a significant part of activities of various entities, including public institutions. This applies in particular to cultural resources of significance to the collective identity of various groups including ethnic and national groups. Digitisation enables the protection of these resources from destruction and oblivion. Digitisation of resources that have been recognised by a particular community as elements of its cultural heritage is an important component of cultural policies and the "bottom-up" activity of entities for whom the preservation of cultural contents is of high importance [Dzięglewski et al. 2017].

The issue of cultural heritage digitisation became a subject of interest of Polish authorities as late as the beginning of the 21st century, even though initiatives related to resource digitisation had been undertaken much earlier. Digitisation has been carried out by libraries, museums, archives and a variety of other institutions. At present, there are numerous initiatives related to the digitisation of various library, audiovisual, museum and archival collections, historic monuments and natural features [Dzięglewski et al. 2017].

Digitisation of photographs, manuscripts, maps, books and other objects which are part of cultural heritage is currently ubiquitous. It is also intensely supported by modelling and three-dimensional, digital visualisations [Bunsch et al. 2011]. Archives actively digitise their collections or are planning to do so. It is becoming increasingly clear that if information from analogue sources is not made available in the digital form, it will fail to reach the vast majority of potential recipients [Conway 2015].

The history of digitisation is relatively short, therefore the understanding of this issue is still evolving, both logically and terminologically. This in particular applies to the very term "digitisation" that is used interchangeably with the term "digitalisation" [Paradowski 2010]. "Digitisation" is most commonly used to describe a process that involves computerisation, informatisation and popularisation of the Internet. This term is also understood as actions undertaken in order to increase the access to the Internet and online resources for citizens, and to use electronic mechanisms in streamlining the operations of public administration authorities [Dzięglewski and Juza 2013].

According to the National Film Archive – Audiovisual Institute in Poland, digitisation is the conversion of analogue materials to a digital form by the scanning or photographic method, followed by further computer processing of the obtained images to a form enabling their publication online. According to Poland's National Institute for Museums and Public Collections (NIMOZ), digitisation means obtaining a digital, most faithful representation of an object and metadata that describe it and contain technical details. Metadata i.e. the data about digitised material are particularly important to various types of archives, as they allow collections to be organised. They indicate the context in which particular contents were found, so that they are easier to find later on [Dzięglewski and Juza 2013]. In the narrow sense, digitisation is the transformation of an object in the analogue form into the binary form. "To digitise" means to transform into the digital form. However, narrowing digitisation down to the very process of analogue-digital conversion may lead to neglect of other components that are of importance for digitisation to be carried out effectively [Paradowski 2010]. This is because digitisation is the entirety of processes resulting in the creation of digital reproductions. Not only is it comprised of obtaining a digital equivalent and metadata (paradata) but also the generation of descriptive metadata and various associated operations, including data collection, structurisation, processing, management, archiving, protection, exchange and use. In a broad sense, therefore, digitisation is a comprehensive process [Bunsch et al. 2011].

Digitisation is often understood as a mere automatic scanning of documents. Meanwhile, many specialists are indeed involved in this process [Kuczyński 2019]. The scope of operations for each project aimed at the digitisation of collections is very extensive. In most cases, analogue objects require adequate preparation [Supraniuk 2019]. Therefore, digitisation includes all the processes leading to the formation of a digital reproduction of a particular work, and the entirety of processes necessary to preserve it and make it available [Dzięglewski and Juza 2013].

Digitisation means creating digital reproductions of material resources, or converting analogue records into a digital form. The process involves transforming an analogue form or an analogue carrier into a digital surrogate. Therefore, the digitisation process requires the existence of physical, analogue originals. The foundation of digitisation is to create a structured and systematised electronic inventory without which visual documentation is only a set of graphic files [Bunsch et al. 2011].

The digitisation process is time-consuming, costly and often tedious; it also requires that a clear and consistent strategy for action be devised [Supraniuk 2019]. From the perspective of the use of modern technologies, the most important factors in the digitisation process include: the selection of a digitisation standard, a description of collections and the method for archiving digital representations [Zachara 2016]. The digitisation process is carried out by means of digital formatting in which the information recorded on an analogue carrier is converted into a sequence of zeros and ones, which, using a specific encoding, is recorded on a computer. In this way, the "continuous" analogue signal is converted into a "discrete" signal i.e. one recorded in the form of symbols. The purpose of digitisation is to preserve material resources, protect them against destruction, and make them accessible [Gołda-Sobczak 2013]. In relation to works of art, digitisation means the conversion of a real object into its digital equivalent. A digital representation should be characterised by appropriate reproduction quality resulting from the technique and equipment used. In addition, digitisation can be understood as an automated measurement process that yields digital data with constant and well-defined parameters [Bunsch et al. 2011].

Digitisation can also be a bottom-up process that involves people and institutions from outside the group of entities dealing with it traditionally or commercially, such as specialised companies, libraries, archives or museums [Wilkowski 2013]. There are numerous digital repositories developed by non-governmental organisations, associations and individuals [Dzięglewski et al. 2017]. Enthusiastic "amateur digitisation", a phenomenon that is frequently devalued by professionals, is sometimes a source of rich cultural heritage resources, and often enables access to unique collections [Terras 2010]. At this point, it is worth stressing that the inclusion of "amateurs" in the digitisation process does not make heritage a "digital trash bin". Digitised works resulting from bottom-up initiatives are often made in a professional manner [Tarkowski et al. 2016].

3.1.1. Digital artifacts

An artifact is an object created by the human mind and human work, as opposed to nature's creations (from Latin words *arte* and *factum*, which mean "by or using art" and "something made", respectively [Witosz 2015]. In the field of archaeology, an artifact is an object showing traces of processing, as opposed to natural objects; in other words, it is a relic of the past, or a product. On the other hand, a cultural artifact is a purposefully produced or transformed object with a specific form, selected purpose and an assigned value.

In anthropology and the sociology of culture, an artifact is a manifestation of the functioning of a particular culture. From the perspective of fantasy and science fiction, an artifact is a valuable item that is usually difficult to acquire, intended for a specific purpose and equipped with the so-called “powers” (properties). In fantasy, artifacts are often of a magical, divine or supernatural origin. The acquisition of an artifact enhances physical, intellectual etc. capabilities. In science fiction, artifacts are usually the work of a highly developed, alien or lost civilisation. Such artifacts are often a part of a (fictional) plot, or they can be considered equivalent with a fragment of a code, if they are associated with a computer program. On the other hand, in the context of digital graphic quality, an artifact is any undesirable or unintended changes taking the form of errors, defects, disturbances or distortions of image resulting from their digital conversion e.g. the application of lossy data compression algorithms (for audio files, they will be e.g. reverberations or echoes). A set of artifacts comprises objects situated within the real and virtual space, both artistic and functional. Artifacts are usually rich in contents and values [Witosz 2015].

It appears rather strange that digital artifacts e.g. software have material properties, since people usually think of materials or materiality as of physical substances such as wood, steel or stone. However, the “materiality” of digital artifacts is increasingly talked about in public discourse [Leonardi 2010].

Interaction design is a process of shaping digital artifacts; digital technology offers potentially unlimited possibilities of creation. This is a material in a sense completely devoid of recognized properties and, at the same time, capable of taking on almost any property. Recognising that the fundamental property of digital technologies i.e. a specific digital DNA is the interactive objectivity/modularity means that the most important attributes of digital technologies are those which determine their flexibility and freedom of creation, and in this sense this material can indeed be described as having no publically defined properties [Składanek 2011].

Virtual artifacts are, in other words, virtual creations (which are objects rather than existing in physical space). Virtual curation of artifacts involves the selection of objects i.e. analogue, tangible artifacts, usually rare and fragile relics of the past, which will be reconstructed in the form of a digital model and take on the form of a digital artifact. Computer tomography technology has significantly increased the opportunities to detect and visualise the internal structure of materials, and the geometrical production of digital artifacts. Virtual reconstructions of 3D cultural heritage objects are being increasingly generated [Zhang et al. 2012].

Three-dimensional visualisation is an effective way to present cultural heritage artifacts. Appropriate hardware and software enable the generation of a virtual equivalent of any object i.e. the so-called virtual artifact, or a digital surrogate. A laser scanner records artifact details. The scanner software enables the edition of digital models. Then, on their basis, plastic replicas are printed (in various sizes). These, in turn, can be painted to reflect the character of the original to the greatest extent [Means et al. 2013, Means 2015, Sooai et al. 2017]. The presentation of a digital object is not exposed to the effects of external factors which, in the case of the original, may lead to its degradation (e.g. microclimate, temperature or light), and the display via digital devices renders it generally available.

An example of a digital artifact is the first-ever web page. It is assumed that the inventor of the World Wide Web (WWW) is Tim Berners-Lee, a British scientist who developed the concept of WWW in 1989 while working at the CERN (The European Organization for Nuclear Research, Geneva, Switzerland) [Berners-Lee 1998, Choudhury 2014]. Since then, Berners-Lee has been playing an active role in guiding the development of Internet standards such as the languages of tags used to create web pages, and in recent years he has been promoting a vision of a semantic network [Naik and Shivalingaiah 2008]. The concept of the WWW was developed in response to the demand for fast and automated exchange of information between scientists from universities and institutes from all over the world. On 30 April 1993, the CERN made the World Wide Web available in the public domain, which resulted in a rapid development of the network.

The first web page was dedicated to the World Wide Web project, and was hosted on a NeXTCube computer. The first-ever internet address was http://info.cern.ch. The first web page contains neither flashy graphics nor video clips; it is just a text page on a white background, including numerous hyperlinks. It is worth mentioning that the first web page and the first WWW address were restored and made available to Internet users as part of activities undertaken by the CERN. Their aim was to preserve and make available certain digital resources associated with the emergence of WWW.

For many people, searching for the first web page appears to make no sense. Even the simplest website created these days by a novice is many times more advanced than the websites created more than two decades ago. However, understanding this phenomenon may be facilitated by a certain analogy. The following question can indeed be asked: why do millions of people travel to Europe to see the original painting of Mona Lisa, while its copies or subsequent variants are generally available. Professor Paul Jones (University of North Carolina, Chapel Hill) believes that no matter how perfect a copy or other version of a work is, it is still just another copy or another version. The more derivatives, the greater the desire to get to know the original [The Associated Press 2013].

3.1.2. Digital surrogates and digital proxy

An artifact (an object, an item, a work) can be either an analogue or a digital product. Digital artifacts may exist only in a digital form or be a digital reproduction, a replica, a substitute i.e. a digital surrogate (Fig. 5).

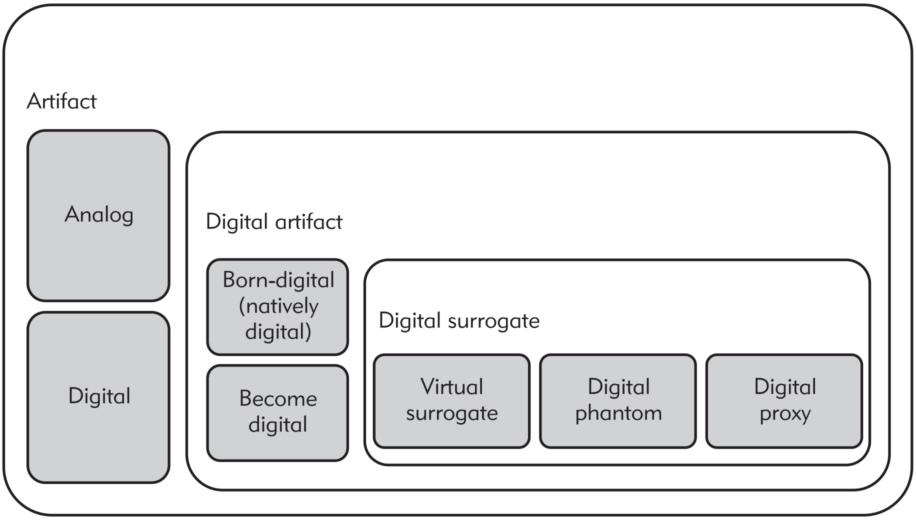

Fig. 5. From a digital artifact to digital proxy
Source: Authors' own study

The rapid development of digital technologies adds a new quality to the preservation of cultural heritage by providing an opportunity to create and make available digital representations of historic objects [Bunsch et al. 2011]. In such a case, a digital object is an object resulting from one or more processes of the digitisation of a physical (analogue) object, its part or multiple such objects, and regarded as a whole [Paradowski 2010]. Digitisation results in digital reproductions, specific "digital replicas" also called "digital surrogates". Digital representations serve as a certain type of a substitute for the original. A surrogate (Latin *surrogare*, *subrogare* – "to choose someone else as a substitute") is an object of a substitute character, an ersatz for an object. This term is used to refer to a wide range of objects, mostly of a material nature. A surrogate is something that stands in for or takes the place of something else, in this case the original source. The preservation of the surrogates that result from large-scale digitization is premised partly upon their long-term cultural and research value, rather than on their distinctive qualities, which may fall short of the standardized ideal [Conway 2015, p. 52].

Digital surrogate is a term of art used in the libraries and archives to refer to any digital representation of a work that exists in the physical world (a thumbnail, a metadata record, a digital image) [Rabinowitz 2015, p. 29]. More commonly, however, the term indicates a faithful digital copy that seeks to represent an analogue original as accurately and in as much detail as possible: "By definition, a surrogate can be used in place of the original. If a surrogate is electronic, the same files can be used both internally (to protect the original when the surrogate is of sufficient quality and accuracy to stand in place of the original), and externally (to provide wider access for those who might otherwise be unable to view or study an original)" [Grycz 2006, p. 34].

Digitisation is the conversion of objects preserved in an analogue form to their digital surrogates i.e. digital equivalents. Large-scale digitization is generating extraordinary collections of visual and textual surrogates, potentially endowed with transcendent long-term cultural and research values. Understanding the nature of digital surrogacy is a substantial intellectual opportunity for archival science and the digital humanities, because of the increasing independence of surrogate collections from their archival sources [Conway 2015, p. 51]. Digital surrogates have been created in order to safeguard the documentary heritage, primarily the material one. Their emergence is associated with the development of digital systems, and in particular computers and peripheral devices that allow electronic resources to be acquired, stored, reproduced and shared [Kowalska 2005]. The convenience and efficiency of access to digital surrogates create a lively and interactive communication between the evidence of our past and our present human condition, as well as with our hopes and aspirations for the future [Conway 2015, p. 52].

Digital files facilitate the access to information in a particular manner. Moreover, they allow one to notice what has been difficult or impossible to observe in the original. Easy access to digital surrogates is a convenience for researchers planning a research strategy. Digital surrogates enable collecting research materials from all around the world. They also enable both the combination of different collections and the comparison of objects that can be compared only due to their availability in the digital form. Digital objects often provide sufficient information about the originals, even if their quality is low. By using illustrative images, one can get acquainted with an object to make sure as to whether or not it is necessary to go and see the original [Smith 2002].

Digital surrogates significantly restrict the degradation of historic objects because they are often used at exhibitions or subjected to testing instead of the originals. An example of a digital surrogate may be a three-dimensional replica created in a high resolution, which stores data on a particular item in digital files (e.g. copies made under the project Scan4Reco 2015–2018, Horizon 2020). The selected object or item e.g. a mural, a painting, a metal object or a sculpture is scanned in advance. Cameras with the depth detection function convert a scanned item to digital layers, which allows details invisible to the naked eye to be viewed. This enables a non-invasive analysis and identification of damaged areas, and eliminates the need for collecting samples from the surface, which may damage works of art. Then, computer algorithms create simulations of how the item will look like after many years [CORDIS 2019].

Digital archives accept and preserve digital content for long-term use. Increasingly, stakeholders are creating large-scale digital repositories to ingest surrogates of archival resources or digitized books whose intellectual value as surrogates may exceed that of the original sources themselves [Conway 2011]. In digital libraries and archives, surrogates are crucial for browsing large distributed collections. In browsing, surrogates provide an important alternative to primary objects as they take far less time to examine and provide enough semantic cues to allow users to assess the need for further processing of other surrogates and the primary object [Greene et al. 2000]. Jacobs and Jacobs [2013] proposed the "Digital-Surrogate Seal of Approval" (DSSOA) as a simple way of describing digital objects created from printed books and other non-digital originals as surrogates for the analog original. The DSSOA denotes that a digitization accurately and completely replicates the content and presentation of the original. DSSOA is based on the belief that one base-line, minimum method for the digitization of books is the capturing of the original layout and presentation of the analog work – a digital surrogate for the original analog object [Jacobs and Jacobs 2013].

The digital surrogates of analogue sources can be used for a wide range of purposes, such as a truthful representation of the original or a global reference to the original [van Horik et al. 2004]. Digital surrogates of "real world" cultural heritage can robustly communicate the empirical features of cultural heritage materials. When digital surrogates are built transparently, authentic, reliable scientific representations can result. Information about the digital surrogates stored in a semantically rich "common language" permit concatenation of information across many collections and demystify complex semantic query of vast amounts of information to efficiently find relevant material. Digital surrogate archives remove physical barriers to scholarly and public access and foster widespread knowledge and enjoyment of nature and our ancestors' achievements [Mudge et al. 2007]. Digital surrogates are digital anchor points that can serve as references for participation and discussion. The availability of these surrogates is crucial for people to participate in digital heritage [Häyrinen 2012, p. 12].

The product of a digitising process is often called a digital surrogate. However, since the targets of digitisation vary greatly, not all digitisations are surrogates. A significant part of digital heritage consists of the product of the digital reproduction of pre-existing works. This digital "double" does not claim to be an identical copy of the initial work, but only a representation of it [Abid 2007]. The process of digitisation is not just a simple analogue-digital transformation. Jim Lindner [2006] gives some examples of scanning of paper document: What is the color temperature of the lamps during the scan? What is the amount and distribution of bits available to represent the color? Is the color space compressed in any way? Are there optics in the scanner and if so, what is the distortion across the field (very few lenses are perfect)? What are the errors in registration? What is the linearity and sensitivity of the array? Lindner [2006] uses a term "digital proxy" about digitisations that are not meant to be a surrogate – the closest fidelity to the original object – but that are good enough for viewing and referencing purposes. Another example provided by Lindner is analogue video materials that are digitised and compressed using a "lossy codec" (the so-called lossy compression). Conversion of this type results in a loss of some information but reduces the file size which, in turn, facilitates the dissemination of the material, for example through mobile devices. Moreover, "digital proxy" can be used as a reference point. A digital miniature copy is often sufficient to identify an object, for example in the collection management process [Häyrinen 2012].

Certain types of digital surrogates are so-called "digital phantoms"; this term was used by Campagnolo et al. [2016]. They borrowed the idea of phantom tests from medical physics, and applied it to cultural heritage imaging in order to evaluate methods for recovery of writing from multispectral images of a palimpsest. Phantoms are essentially a simplification of a physical research problem where tests and experiments can be carried out quickly and safely. Phantoms are used to test and compare new systems, calibrate prototypes, and iterate improvements quickly. Phantoms in medical physics research are similar to digital surrogates in the humanities; just as these surrogates allow the study of cultural heritage artifacts without further damaging the originals, phantoms allow experiments to be carried out without risking harm to patients [Campagnolo et al. 2016].

3.1.3. Digitisation drawbacks

Until recently, all information was recorded in an analogue form, which implied a continuous stream of information of different densities and types. Analogue information can include anything, from subtle tones and shades of light visible in photographs to changes in the sound volume, tone quality and the voice tone and pitch recorded on a tape. Where such information is input into a computer and converted into zeros and ones, its nature changes. Digitally encoded data do not represent the infinitely differentiated nature of information as faithfully as analogous forms of recording [Smith 2002].

Digital files get old, and so do the hardware and software used to open and read them. For example, a microfilm, when made on a silver halide-coated film and stored in a stable environment, is supposed to last for several centuries. Only light and a lens are needed to read it. However, reading digital files requires both hardware and software. These, in turn, become obsolete relatively quickly, and the information they contain may become unavailable. Recovery of data encoded in obsolete file formats and recorded on old carriers is costly and labour-intensive, if at all possible. Additionally, other hazards may arise. Apart from IT infrastructure failure, malware or interference by unauthorised persons pose a potential risk [Supraniuk 2019].

Digital information is not recorded on a data carrier in such a manner as a text is written on parchment or engraved on a rock, and its durability is shorter. What is more, a digital equivalent of a work of art, even though it provides an opportunity to preserve and safeguard it, accepts interference with the degree of the object's reproduction. Digital texts are neither final nor finished. They are not preserved in terms of their content and form either, as they can be modified without leaving any trace of amendments [Smith 2002]. Therefore, a danger exists that a digital version of an object may be challenged on its authenticity but, however, not only because of the possibility for interfering with the file content. An object subjected to digitisation is completely transformed. During digitisation, even if carried out at the highest standard, there will always be a certain loss of information in relation to the source object, similarly as in the case of analogue copying. Therefore, a digital surrogate is not always a faithful equivalent of the original. This is particularly noticeable e.g. when digitising archival film materials. Resolution of photosensitive materials is a concept difficult to define and convert into numerical values. The image on a cinematograph film, created by irregularly distributed silver halide crystals that provide the characteristic impression of grain and optical density, does not enable simple grain-to-pixel conversion [Supraniuk 2019].

The quality of a digital surrogate may vary. The data produced in the digitisation process may have different levels of detail and accuracy, hence their quality should be determined by their intended use. A conservator's documentation parameters will be different from those of conservation documentation [Bunsch et al. 2011].

The success of digitisation is largely determined by proper cost estimation. Digitised information is transferred to the environment that is based on a technology that constantly generates costs. The more information is converted into the electronic form, the more the costs of providing access to it will increase. It has been compared to a "digital black hole". Continuous funding is necessary, otherwise the data will be lost due to e.g. carried damage, obsolete formats or an outdated technology [Palm 2011]. Moreover, digitisation often results in large-sized digital files whose handling (storage, browsing, editing etc.) requires a complex and expensive computer infrastructure [Supraniuk 2019].

An important aspect of digitisation is the restrictions on copyright on digitised objects. The scope and development of digitisation projects are restricted by institutions' budgets and copyright regulations, particularly for works of an unclear status, the so-called orphan works [Wilkowski 2013]. The issue of the conflict of interests i.e. copyright versus the users' right to access to information and knowledge is constantly raised [Zachara 2016]. Moreover, mass digitisation projects and making archive and library resources available online are not usually coordinated, and the selection of specific resources is largely determined by their type and copyright status [Thomas and Johnson 2012].

The basic feature of any given digital surrogate is its immateriality. For the traditional (analog) cultural heritage objects, this can be a serious problem. Certain features of the original cannot be reproduced in digital or even virtual realities. Indeed, digital surrogates enable detailed analyses but the feeling of being in an archive, the emotions associated with the contact with an artifact, the touch and the smell make up the uniqueness and completeness of the experience. Emotions, affects and impressions are the basic components of experiencing heritage; however, digital equivalents fail to ensure those [Petrelli et al. 2013].

3.2. Data migration

Heritage, culture, understanding and definition of it, is a vast and complicated human sphere evolved through the centuries and manifested in language, writing, art, architecture, etc. Digital representations of reality, either past or present, are currently tied to a myriad of technology schemes that can vary greatly in the presentation form and style of digital heritage information [Foni et al. 2010, Thwaites 2013]. Researchers and digital heritage media creators now have access to various technological tools and a wide range of affordable hardware and software [Hemsley et al. 2005]. Preservation of digital objects is achieved through, *inter alia*, migration and emulation [Anderson et al. 2010]. Migration is a process of transforming digital files from one format into another that is appropriate to the software and hardware currently in use. The purpose of the format change is to enable access to the file content in the easiest way possible at any particular moment. Migration involves changing a particular file format to another, newer and valid format. It allows the original format and nature of the file to be changed, and gives priority to access more than file originality [Pearson and del Pozo 2009].

Data migration has many advantages, although it is also sometimes criticised. In a longer-term perspective it may be costly and thus unprofitable, and susceptible to errors, partially successful and even, at some point, impossible to carry out [Rothenberg 1999]. Moreover, each data migration, each format change, each processing or conversion makes the output object move away from the original [Bearman 1999]. During migration, unique file properties may be lost. Therefore, after multiple migrations, it may be difficult or even impossible to determine the original attributes of the (most recent output) file.

3.3. Emulators: vernacular archivists

It is possible to migrate complex programs partially, from a platform to a platform and this process can be continued indefinitely. This, however, would be time-consuming and labour-intensive, which puts such measures into question. Distinctly, emulation is a solution that allows a large number of various digital objects dependent on a particular (obsolete) hardware platform to be made available on a substitute platform [Gladney 2008].

In recent years, migration and emulation have emerged as the main strategies used for digital preservation. Lorie differentiates between the archiving of data and the archiving of program behavior. While the first can be done without emulation, it cannot be avoided for the latter [Lorie 2001]. Emulation is the restoration of an entire digital ecosystem that comprises software and hardware. This ecosystem is characteristic of a particular digital age, and enables the launch of software from that age. All this takes place in the valid, current ecosystem which does not allow archaic software incompatible with the current standard to be launched [Guttenbrunner et al. 2010]. Emulation is a process of creating a "virtual" (emulated) equivalent of the original environment, that is used to gain access to files with specific attributes. Emulation of a particular environment is carried out using modern hardware and software. It allows one to retain the access to the original content of files (without changing this content) using an emulated computer. Emulation does not change the file format (which may occur during migration); therefore, it causes no losses in its content [Pearson and del Pozo 2009]. Emulation offers a logical possibility for perfect reproduction of an obsolete hardware platform's behavioural characteristics in the current system [Anderson et al. 2010]. According to Brand [1999], emulators are vernacular archivists that are "the only hope" for the future of keeping archives of complex digital artifacts.

The ability to accurately reproduce digital materials is usually limited by the emulator capabilities. Effective emulation is not possible in all cases. Certain programs may contain copy-protection or activation protocols which may limit or even prevent a program from being launched in an emulated environment. Not without significance is the fact that emulations themselves may be classified as "file formats" and, as such, are subject to the same rules (e.g. ageing) as other digital contents. Importantly, emulation provides only a limited reproduction of the original access environment. There are input devices whose reconstruction may be impossible [Pearson and del Pozo 2009].

The key term associated with the emulation is the phrase "original experience" that refers to the need to preserve the experience of use "as it really was". This is particularly important for emulation, where the impression of authenticity i.e. the most accurate preservation of original software properties while taking account of the effects typical of the platform being simulated is the main criterion for its assessment. However, the reconstruction of the experience "as it really was" is often possible only on the original equipment.

During their lifetime, software systems are subject to maintenance with the aim to e.g. introduce new functions or render software competitive in relation to alternative products, repair defects or adjust the software to new environments and architectures. Due to time pressure, limited resources or the lack of discipline in the maintenance process, these operations tend to destroy the software system structure by increasing the complexity of the source code and hindering the understanding and maintenance of the system in the future [Canfora et al. 2014]. Parnas [1994] called this phenomenon "software ageing": similarly to the ageing of people, software ageing is inevitable but, just like for the ageing of people, there are things that can be done to slow down the ageing process or even to reverse its effects. It is not possible to prevent software from ageing but it is possible to understand its causes, take measures to limit its effects, reverse some damage and prepare for the day on which the software will no longer work.

Chapter 4

Protection, preservation and popularisation of cultural heritage

The functioning of the Internet space as a place for communication, access to information and exchange of opinions contributes to the development of new forms of the promotion of cultural heritage and making it available [Pawłowska and Matoga 2014]. Cultural institutions such as museums, archives or libraries have for centuries been responsible for collecting, storing and promoting cultural heritage. Thanks to new technologies, this important mission can be carried out on an unprecedented scale. as culture may be disseminated by means of digital files via the Internet. What is more, due to new technologies, cultural resources have begun to be perceived as a catalyst of socio-economic development [Janus et al. 2014].

4.1. Historical software collections

The first computer-program products were sold in the mid-1960s [Campbell-Kelly 2005]. Since then, millions of programs have been developed. It is not possible to archive or even to catalogue all of them. Selected programs, recognised as cultural heritage of international importance, are available in the historical software collection provided to the public in the Internet Archive.

The digital library Internet Archive is most often presented through the prism of the Weyback Machine – a service of collecting and sharing archival website copies. Meanwhile, the Internet Archive collects and shares also a variety of multimedia resources, e.g. television archives or radio broadcasts from the 1950's. as well as games and programs [Scott 2013]. The oldest programs ran on very rare hardware. They are now made available for scientific, educational and historical purposes.

Historical Software is a collection of selected, groundbreaking and historically important software, often the most popular at a particular time or the first of its kind, such as Visicals (Software Arts, 1979) which was the first program to handle spreadsheets (due to this program, the Apple II computer (Fig. 6) became a useful business tool two years before the introduction of IBM PC), or WordStar (MicroPro, 1981), by the mid-1980's a leading text editor.

A particular type of software is (arcade, video, computer) games that are often regarded only as a form of entertainment, whereas they have had a significant influence (e.g. cultural) on the society at the turn of the century [Connolly et al. 2012]. Interactive fiction and video games are part of our cultural heritage. Digital games are a major part of popular culture. They are also an important part of the

Fig. 6. Apple II in typical 1977 configuration with 9'' monochrome monitor, game paddles, and Red Book recommended RQ-309DS cassette deck
Licence: CC BY-SA 4.0 (author: FozzTexx)
Source: commons.wikimedia.org

history of play and, as such, they deserve to take their rightful place in our cultural legacy [Barwick 2011]. The public interest in early video games is high, as exhibitions, regular magazines on the topic and newspaper articles demonstrate [Guttenbrunner et al. 2010]. Games and programs are, in many ways, “dying media” as their use depends on hardware and software in their original configuration, which have a limited lifespan. Long-term maintenance of original equipment in a good technical condition is becoming increasingly difficult with the passing of the years [Garda 2014, Garda 2017]. Newman [2012b] devoted a lot of attention to this problem and provoked a discussion, including the following suggestion: “Let us allow games to die. We will never be able to preserve them as they once were”.

Archaic games and leitmotifs of these games are enjoying a growing interest. New products offer more and more solutions applied in products of the 8- or 16-bit era. More and more enthusiastic gamers can be heard saying that “games used to be better”, despite the impressive graphic effects available nowadays. Independent game developers try to refer to the gaming experience from their childhood, and to infect younger generations’ minds with their passion. So-called “retro zones” with exhibitions devoted to games, computers and consoles from the 1970’s or ‘80’s are emerging increasingly often [Szewerniak 2018].

4.1.1. Introduction to the history of games

Over the past 30 years, the video game industry has become a multi-billion-dollar business. More people spend their time playing computer games than ever before. However, it was not always like that. Everything has its origins.

The first video games emerged in laboratories and research centres in the 1960’s and 70’s. The pioneering programmers were not aware of the potential of games, partially due to the enormous amounts of hardware required to start them. The intertwined histories of the games Computer Space (Nolan Bushnell and Ted Dabney) and Pong created by Allan Alcorn and Nolan Bushnell show the complicated historical relationships among the arcade, computer and video games, and the long way they came from “university games” available only within university walls to the commonly available entertainment and educational games [Lowood 2009].

The first “computer game” was probably the game OXO (“Noughts and Crosses”) by Alexander S. Douglas, which was created in 1952. The game OXO was developed to be played on the EDSAC computer (Fig. 7). EDSAC was the world’s first computer with programs which regularly performed computing tasks. Designed and constructed at Cambridge University in the United Kingdom, EDSAC performed its first computations on 6 May 1949.

OXO is a “noughts and crosses” (Os and Xs) game played against the computer; although the game never gained popularity, since the EDSAC was available

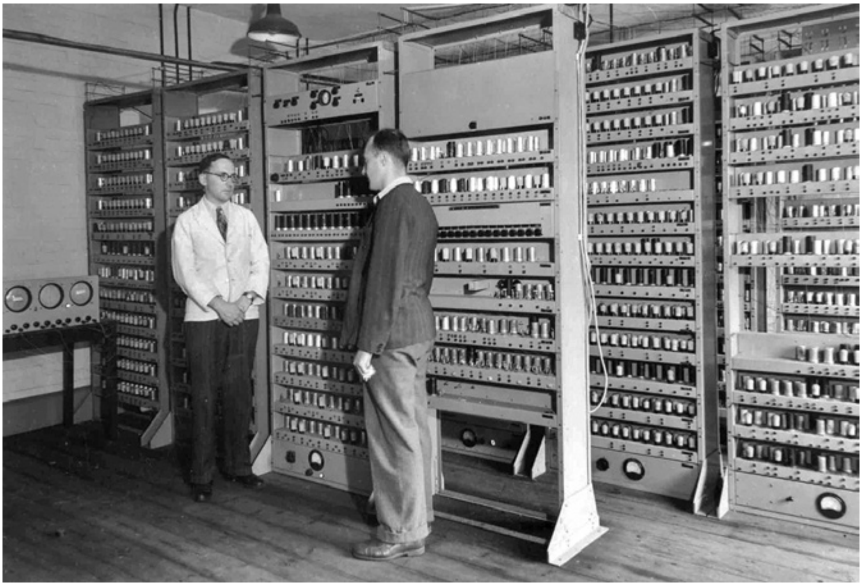

Fig. 7. EDSAC digital machine components

Source: commons.wikimedia.org

only in Cambridge, but it was a milestone in the history of video games [HVG 2019]. In a way, the game resulted from scientific work. A. Douglas wrote his PhD thesis on human-computer interactions, and illustrated it with just the graphic game of noughts and crosses, displayed using a cathode lamp. The game is currently accessible in the emulated EDSAC environment [Winter 2019].

The first “real” interactive computer game is considered to be “Tennis for Two” developed in 1958 by a physicist William Higginbotham for people visiting the Brookhaven National Laboratory (Upton, New York). “Tennis for Two” was the first ever table tennis simulator. The image was displayed on an oscilloscope (Fig. 8). The game was designed to instruct players in the effects of gravity [Overmars 2012]. The game was controlled by an analogue computer which “mainly comprised resistors, capacitors and relays but, where a quick change was needed i.e. when the ball was in play, switching transistors were used” [HVG 2019].

Another early computer game was Spacewar! developed in the years 1961–1962 by students of MIT (Massachusetts Institute of Technology, Cambridge, MA, USA), namely Martin Graetz, Stephen Russell and Wayne Wiitanen, on a PDP-1 computer [Overmars 2012]. PDP-1 (Programmed Data Processor-1) is the first computer of the Digital Equipment Corporation PDP series, manufactured in 1959. Indeed, the PDP-1 had a phenomenal appearance (Fig. 9).

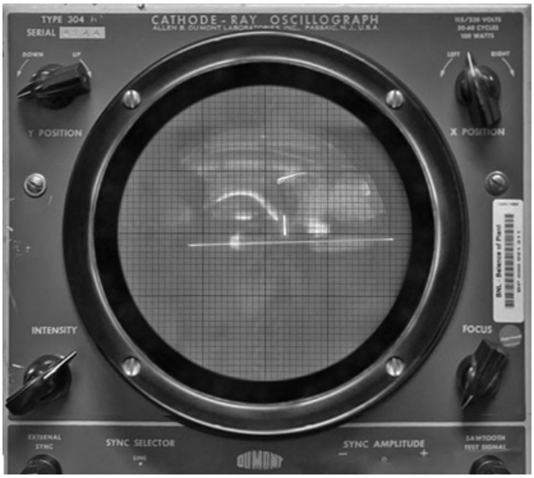

Fig. 8. Tennis for Two on a DuMont Lab Oscilloscope Type 304
Licence: CC BY-SA 4.0

Source: commons.wikimedia.org

Fig. 9. DEC PDP-1 Demo Lab at Mountain View's Computer History Museum
Licence: public domain

Source: commons.wikimedia.org

Even though the game Spacewar! looked like a video game (Fig. 10), it used no video display and therefore should not be regarded as such. It was, however, a remarkable predecessor of the games to be played at homes later, in the 1970's. Currently, the game can be played in its original form on any computer with Java enabled (the game is started using the MESS emulator [Winter 2019]. In 1966, Sega released an arcade game "Periscope" which, while not being a computer game *per se*, demonstrated the possibilities offered by gaming machines.

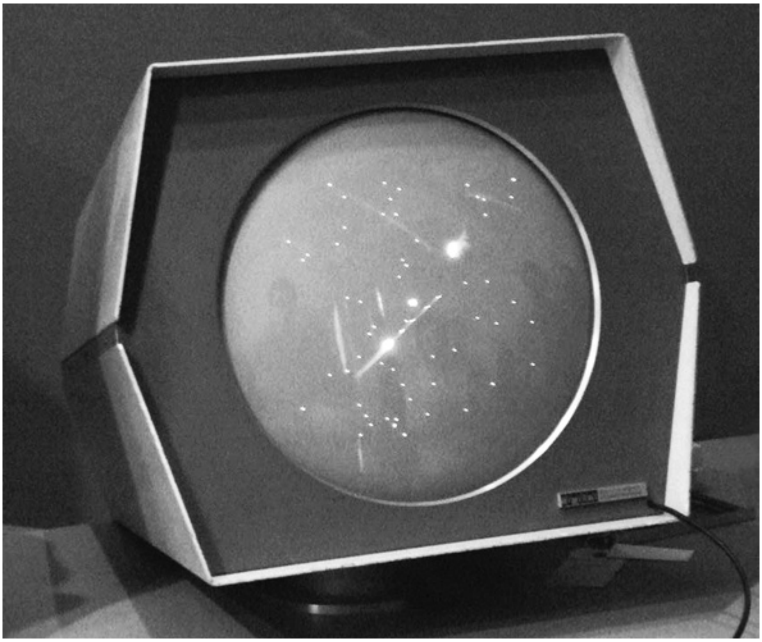

Fig. 10. Screenshot of a PDP-1 computer running Spacewar
Licence: CC BY 2.0 (author: Kenneth Lu)
Source: commons.wikimedia.org

Winter [2019] believes that the "true history of video games" began with Ralph Baer in 1951. The important thing is that a video game was defined in the 1960's, before technologies enabling game-playing on a computer emerged. A video game is a device that displays games and uses RASTER VIDEO equipment i.e. a TV set, a display unit, etc. In the 1950's and 60's, computers were not only extremely expensive but also used a technology that did not allow them to be integrated with the video game system. Only mainframe computers allowed more than one game to be played (a mainframe computer is a large-sized, institutional machine designed to serve multiple users).

The first video game prototypes were created in 1966 on the initiative of Ralph Baer, although he had already had an idea to develop a TV set with a video game 10 years earlier. This is why Ralph Baer is regarded as the inventor of the video game. It is commonly believed, however, that the first game was designed in 1947 (the date of the patent). This very simple game was displayed on a cathode ray tube (CRT) display, and was designed by Thomas T. Goldsmith Jr. and Estle Ray Mann. The system made use of eight vacuum tubes (four 6Q5 triodes and four 6V6 tetrodes), and the system simulated shooting a missile at a target. The idea was inspired by radar displays used during the Second World War. Several knobs allowed the curve and velocity of the missile-representing point to be adjusted. Since graphics could not be rendered electronically at that time, the game creators placed cover plates on a small CRT display unit. Since the CRT unit generated no video signals such as e.g. an ordinary TV set or a visual display unit, from the technical perspective it was not a video game. It has been assumed, however, that this is the earliest system designed to be played on a CRT display unit.

The years 1970–1979 are often referred to as the golden age of arcade games. The first commercial use of games occurred in slot machines (arcade games). Arcade games are a classical genre of video games running on specialised machines. A machine was activated after a coin was inserted in it. The first arcade video game "Computer Space" was launched in 1971; however, it was not commercially successful. Shortly afterwards, its creators established the company Atari [Overmars 2012].

In 1972, an arcade game Pong produced and released by Atari was launched to the American market (Fig. 11). The game initiated the development of a multi-billion-dollar computer game industry. The game "Pong" was a two-dimensional table tennis simulation made available as a coin-op game [Carnagey and Anderson 2004].

Fig. 11. Atari Pong arcade game cabinet
Licence: CC BY 2.0 (author: Rob Boudon)
Source: commons.wikimedia.org

Video slot machines were derived from earlier mechanical games such as e.g. the “one-armed bandit”; this is why designers paid attention to the manual aspects of interaction in the game. Such machines and their earlier, mechanical equivalents conveyed an impression of a spectacle in an amusement arcade. Early arcade games and arcade game parlours (filled with smoke and darkened) were a social phenomenon. However, at the end of the 1980’s, migration of games from the public to the private space began. In the 1980’s, a combination of economic and technological forces moved the game from social, communal and relatively anarchic, early arcade spaces to the controlled environments of the “decontaminated” shopping centre arcade (or the “family entertainment centre”) and to peoples’ homes. This was partly due to the increasing accessibility of personal computers and game consoles in the 1990’s [Connor and Gavin 2015].

Soon after Atari, many other game-producing companies emerged. Both “Breakout” and “Space Wars” i.e. games that used vector graphics for the first time, were released in 1976. In 1980, a popular game “Pac-Man” was developed, followed by “Mario Bros.” released in 1983. Nintendo introduced Game Boy in 1989 as the first portable gaming system. Game Boy was sold as a package with the game Tetris, which made it very popular.

Tetris was designed around 1984 by a Russian mathematician Alexey Pajitnov, and is considered to be the most addictive game in history [Overmars 2012]. In 1988, merely a few years after it was invented, the game Tetris was already the best-selling game in both the USA and the UK.

In the 1990’s, the idea for creating games to be played within a three-dimensional space emerged. Most computers, however, had no appropriate graphics equipment. Therefore, programmers created specific “3D environment simulations”. Probably the best-known game of this type was “Doom” developed in 1993 by John Carmack and John Romero. In fact, Doom is a maze game with a first-person view, combined with innovative (at least at that time) graphics. All this made the game extremely popular.

First person shooter (FPS) is a video game genre in which the action is focused on fighting the opponent, usually with the use of firearms. The player experiences the action through the eyes of the main character who usually can only see the hands and weapon. While playing, the player could move around, explore a three-dimensional environment, and shoot at various characters. Games of this type were full of violence. The purpose of the game was to make the player feel as if they were within a game world, able to fight, kill and be killed. The invention of the genre is attributed to the authors of the “Wolfenstein 3D”.

The two oldest documented first-person shooters are in the Maze War also known as the Maze Game, Maze Wars, Mazewar or, simply, the Maze (1973, a platform of *inter alia* PDS-1D computer) and Spasim.

Maze War is a simple FPS game. Players impersonated a flying eyeball, and navigated through a maze by moving forward or backward or by turning by 90 degrees to the left or to the right. The player could see their position on the maze map, but the locations of other players were not revealed. The aim was simple: find the enemy and shoot them down before they do the same to you. If you shoot the enemy down, you score ten points and the enemy loses five points. It is difficult to overestimate the Maze War legacy, as it is a prototype of FPS shooters, online games and multiplayer mode games. Innovations that are obvious nowadays, such as the radar, game level edition, the observer mode and avatars, have their origins (or at least appeared for the first time) under none other than this title.

"Spasim" is the first game for multiple players – a First-Person Shooter 3D outer space simulation developed for the PLATO network by Jim Bowery (the University of Illinois at Urbana-Champaign, PLATO network). The game allowed 32 people to play in 4 planetary systems, with up to 8 players participating in the game per planetary system. Players could use spaceships whose positions were updated every second. In the first edition of 1974, the game was a simple team game of the Phasers-and-Photon-Torpedoes Star Trek type, combined with the multi-player FPS dynamics. In order to be able to move objects, the knowledge of calculating polar and Cartesian coordinates was required. In this way, Spasim served the role of an educational game, and could be launched in the PLATO network (Fig. 12) that was designed for computer-based education [Bowery 2001].

Fig. 12. PLATO V Terminal with plasma display, 1981
Licence: CC BY 3.0
Source: commons.wikimedia.org

In 1992, Wolfenstein 3D i.e. the first major FPS type game was released (by id Software; the game was also distributed in the shareware version). The game is reputed to have established the canon of first-person shooters i.e. shooter mechanics standard used in modern games of the genre. The game was not allowed to be distributed in Germany due to the presence of Nazi symbols. A video game historian Steven Kent remarked that "part of the popularity of Wolfenstein was due to the fact that the game was shocking. In earlier games, when the players shot at their enemies, the wounded targets would collapse and disappear. In 'Wolfenstein 3D' the enemies collapsed and bled on the floor" [Kent 2001, p. 458]. This resulted in a revolution in the way brutal games were designed. Another major FPS game, "Doom", contained even more violence and blood [Anderson et al. 2007].

In one of the "Wolfenstein 3D" versions, the player impersonated B.J. Blazkowicz, an (imaginary) American soldier captured and taken prisoner by the Nazis during the Second World War. The player's task was to escape from a prison through a maze of passages in the Hollehammer castle and finding evidence of the Eisenfaust operation, a Nazi plan to create an ideal army, while killing everything that moves, both prison guards and guard dogs. In "Wolfenstein 3D", the protagonists had at their disposal deadly weapons including a revolver, automatic firearms and a flamethrower. For those times, the game was literally dripping with violence [Carnagey and Anderson 2004].

Since the time when video games were popularised by "Pong" in 1972, they have become part of mainstream mass culture. Nowadays, video games are played not only on computers and consoles but also on mobile devices including phones. In view of the ubiquity of these devices, games are already being launched not only at home but also at work, at school, on the means of public transport, and indeed everywhere where an electronic device can be used.

4.1.2. Game archiving

Archiving games is not merely a matter of their preserving, archiving or copy preservation, and game-playing itself cannot be reduced to mere "clicking". Video games are used in a variety of applications, and their fans are of all ages and genders [Hartmann and Klimmt 2006, Festl et al. 2013]. The armed forces use games as training simulators ("serious gaming") and as a form of "presentation and promotion". Games of this type are not designed for entertainment but for education or training in various skills. Educational games such as simulators of diseases, business negotiations or the battlefield allow the player to better prepare for situations that can be encountered in reality.

The preservation of games which were popular several or a few dozen years ago does not consist only in making a description or installation files available. Archived games are increasingly often available via emulators launched in a web browser window. Full-screen emulation combined with the original soundtrack offers a substitute for the times when games were launched on computers with the Pentium 200 MMX processor or older ones, e.g. Intel (80)486(dx). In the Internet Archive resources, historical programs originally released e.g. on 5.25' floppy disks or cassette tapes are also available. The library stores and shares software from a variety of platforms, which can be launched in a web browser window via the JSMESS emulator (JavaScript MESS emulation engine). The Software Library collection contains the software developed *inter alia* for the computers Apple II, Atari 800 (Fig. 13) and ZX Spectrum (Fig. 14), including

Fig. 13. Atari 800XL
Licence: public domain (author: MOS6502, modifications by Multicherry)
Source: pl.m.wikipedia.org

Fig. 14. ZX Spectrum
Licence: CC BY-SA 3.0 (author: Daniel Ryde)
Source: pl.wikipedia.org

games, applications, tools, demo versions and operating systems. Moreover, the Console Living Room was made available for game enthusiasts. This archive makes available the oldest console games.

The Polish market of computer games began to develop as late as in the 1980's. This was due to the restrictions arising from Poland's membership of the so-called Eastern Bloc, and resulted in difficulties in accessing computers and consoles as well as software produced in Western countries. Such events as the introduction of martial law in Poland on 13 December 1981 resulted in the ELWRO (Polish producer of e.g. computers) organisational units being militarised, and, after the introduction of restrictions against Poland, in the termination of import contracts for electronic components for the ELWRO [Maćkowiak et al. 2018].

At that time, the delay in the development of national modern resource base of computer components and sub-assemblies was estimated at approximately 10 years. Moreover, exports and imports were controlled by the Coordinating Committee for Multilateral Export Controls (COCOM) which, during the Cold War, imposed a ban on exports by Western countries of modern technical equipment and advanced technologies to the so-called Eastern Bloc countries, including to Poland. The Committee's task was to prevent the so-called Peoples' Democracies (Eastern Bloc countries) and, through them, the Soviet Union from acquiring the most modern products and the so-called dual-use technologies. At that time, it was assumed that, in addition to civilian applications, they could be used as components for military equipment.

The difficulties in the development of Polish computer thought, resulting from the Soviet interventionism, had actually appeared much earlier. In the 1960's, decisions were taken at the highest levels of political and State authorities on the cooperation of the CMEA countries (Council for Mutual Economic Assistance – an organisation coordinating so-called "economic cooperation" within the block of countries subordinated to the Soviet Union) and on the establishment of the Unified System of Electronic Computers (RIAD) in which there was no room for the ODRA computers that, by the way, were considerably more advanced than the Soviet products. Poland was assigned work on the R-30 digital machine [Maćkowiak et al. 2018]. All this had an impact on the development of Polish software and digital equipment.

Not only do the oldest relics of electronic entertainment originate from the United States where software of this type developed most rapidly, but also from Poland. A logical game "Marienbad" is regarded as the first Polish computer game. It emerged at the beginning of the 1960's, and its author was Witold Podgórski. The "Marienbad" was launched on the ODRA 1003 digital machine [Kluska and Rozwadowski 2011]. In later years, various variants of the game, due to being relatively simple in programming, were the second most popular (after the "Noughts and Crosses") type of a computer game present on Polish computing machines. Soon afterwards, the games "The Chess" and "Landing on the Moon" to be played on the ODRA 1003 computer were developed. The game result, however, was printed on a teleprinter and not presented on a display unit; therefore, in the light of the definition, they were not "video games".

In the 1970's, a set of simulation decision-making games was made. The players could manage large enterprises via computer terminals and using mathematical models. After each round of decisions, the machine printed the results achieved by the players, and after the game was over, it calculated the final result which was later analysed by a teacher [Kluska and Rozwadowski 2014]. That's the way the beginnings were.

Games and programs can be important heritage assets, not only of popular culture in general but also of the native folk tradition. The eight-bit computer games which people in Poland played during the Polish People's Republic period are part of history which no longer exists, and its description and preservation is as important as any other studies and attempts at documenting that era [Garda 2014]. Another example may be the history of games in New Zealand, which involves a significant number of games with a local range from the 1980's. Currently, few people in New Zealand and worldwide are aware of this, as no institutional collections exist. This context triggered the establishment of a multidisciplinary team of scientists, whose task was to provide legal and technical knowledge on the preservation of these programs [Swalwell 2009].

Owing to their material and digital "fragility", video games gain in value over time as collectors' items. Melanie Swalwell [2007] compared old games in the "box versions" to expensive porcelain produced by manufacturers such as Wedgwood. In Poland, game preservation is dealt with by organisations such as the Foundation for the Promotion of Retro Computer Science "Old Computers and Games" from Wrocław, or the Museum of Computers and Computer Science History from Katowice [Garda 2014].

4.2. Heritage that has seen the light of day through digitization

Digitisation and the possibility for making available the digital equivalents of works which, for various reasons, could not be exhibited, has gained a considerable interest in Poland and led to the establishment of numerous digital repositories, such as the Krzysztof Komeda Virtual Museum, the Armenian Foundation Digital Library, Digital Kashubia or the Orange Alternative Foundation Archive. The institutional archives are, in a way, complemented by smaller archives, often privately owned, established due to various motivations. An example can be the electronic archives that document the lives and achievements of prominent figures in the world of culture, for example the Marlena Dietrich Archive, the Gilbert and Sullivan Archive, or the Public Digital Agnieszka Osiecka Archive. These archives were established on the initiative of various institutions: the Marlena Dietrich Archive was brought into being by Maria Riva, the actress's daughter, while the Gilbert and Sullivan Archive was established by opera enthusiasts who set up the Gilbert and Sullivan Foundation for this purpose. On the other hand, the Public Digital Agnieszka Osiecka Archive was established by the Fundacja Okularnicy [Kędziora and Góral 2010].

Another example of preserving the artistic achievements of outstanding personalities and preventing them from destruction and oblivion is the project of recording and digitising the posthumous works of the sculptor Franciszek Duszeńko, which is under implementation at the Library of the Academy of Fine Arts in Gdańsk. Due to the substantive and historical value of the objects and their poor state of preservation, digitisation was adopted as the main form of their preservation.

Franciszek Duszeńko was a sculptor, a teacher, a prisoner of Nazi concentration camps during the Second World War, professor and Rector of the State Institute for Visual Arts in Gdańsk (currently the Academy of Fine Arts in Gdańsk). The digitisation carried out with funds provided by the Ministry of Culture and National Heritage in Poland contributed to the protection of the collection, and the Library of the Academy of Fine Arts in Gdańsk could present it to wider audiences [Zelmańska-Lipnicka 2017]. Digital archives operate on various scales and under the wardship of various entities; however, they always take as their mission the preservation and promotion of cultural heritage.

Theatre enthusiasts, researchers and any other people interested in a single piece of information have so far had to search through theatre collections in museums, reading rooms, libraries or archives. Digitisation has made the collections documenting this comparatively ephemeral art take on a digital form, and now they are accessible in the largest data repository i.e. the Internet [Maresz 2012]. For example, the collection of the Artistic Archive and Library of the Juliusz Słowacki Theatre in Kraków (Poland), that has been destined for digitisation, includes 15,000 play-bills of the Kraków theatre from the years 1865–1893 and the Municipal Theatre. This collection is a record of theatre performances taking place during a particular period at the Juliusz Słowacki Theatre in Kraków, and a source of information on the history of the city [Rerak 2014]. Another example which proves that digitisation brings cultural heritage objects to light is the project of digitisation of the archival issues of the "Echo" daily paper which came out in Warszawa in the years 1877–1883. This example shows that digitisation enables the creation of digital surrogates of "delicate" objects like the publications printed on acidic paper which is characterised by considerable brittleness and fragility.

"Echo" was a conservative daily newspaper which paid a lot of attention to cultural, economic and political issues. Representatives of the then intelligentsia, including Władysław Olędzki, Jadwiga Łuszczewska and Adam Asnyk, cooperated with the paper. Thanks to digitisation, the "Echo" paper which before had only been briefly mentioned in general sectoral studies, was given a chance to become well known in scientific literature [Kozakowski 2016]. Another example worth mentioning is the project of digitisation of the most valuable medieval manuscripts, implemented at the Library of the Nicolaus Copernicus University in Toruń in 2013. Under the project, 19 medieval manuscripts originating from the former State and University Library in Königsberg were digitised and published at the Digital Library of the Kuyavia and Pomerania. An important criterion for the selection of objects to be digitised was the preservation state of the codices and the possibility for spreading the pages apart in order to be able to capture e.g. notes on the inner margins with the camera lens. The usefulness of the texts included in the manuscripts for scientific research and the beauty of their external form were also of significance. Thanks to digitisation projects, invaluable medieval codices being part of the common Polish and German as well as European cultural heritage, which had been hidden in storage containers, were made available to wide audiences [Czyżak 2014].

Another example of the use of digitisation in the protection and popularisation of cultural heritage objects is the digitisation of archival resources of Katowice Television. The oldest and, at the same time, the most valuable materials stored in the Katowice Television archives, date back to 1957. These primarily include individual accounts of official events, films documenting the development of industry in the region of Silesia, coverage of sports competitions and cultural and entertainment events. Besides short documentaries about communist party notables' visits to Silesian and Coal Basin mines and steel plants or the progress in the construction of new factories, there are also fragments of performances of workers' theatres operating in the 1960's. Moreover, documentaries from the 1960's and 70's have a high cultural and historical value. The team carrying out the digitisation of resources stressed that the archiving of television materials was not only work but also an opportunity to have contact with art and materials that, thanks to digitisation, have seen the light of day [Fudala-Barańska 2017].

Digitisation allows phonographic objects to be protected from destruction as well. No material, be it paper or a magnetic tape, lasts forever. A magnetic tape that was used for audio recordings is not a durable carrier. The 1/4-inch tapes produced in the years 1940–1960, usually paper-based and not polyester-based, are particularly vulnerable to degradation. In Poland, phonographic materials are digitised *inter alia* by the State archives. An example of this is the New Files Archive which applies the method of recording digital surrogates in the form of WAVE files. Digital audio material is recorded on a server [Gałęzowski 2012].

The unique collections of phonographic recordings being part of the resources of the Majdanek State Museum Archive have also been digitised. Although the materials have been collected in archives for many years, they have not yet been fully used in research, educational or exhibition work. To a large extent, this was due to poor quality recordings and technical limitations. In 2005, activities were commenced with the aim of digitising the collection which, in the case of such sources, is the first stage protecting a collection from destruction. The processing of such archive materials is a time-consuming and complex process due to the need to use specialised technical equipment. Since 2008, work has been underway to establish an electronic database that will facilitate the use of materials. The collection comprises approx. 512 recordings, and is gradually expanding. The largest part of the collection (approx. 400 accounts) are interviews with former prisoners of a Nazi concentration camp at Majdanek and with city of Lublin inhabitants, concerning their fates during the Second World War. As in the case of written memoirs stored in the archive, the substantial majority (88%) are accounts provided by Polish witnesses to history, including former political prisoners. The collection also includes sound recordings provided to the museum by radio stations and other institutions engaged in the issues of the Second World War or memorial site pedagogics [Grudzińska 2011].

4.3. Digital libraries, archives and repositories

Recent years have seen a dramatic increase in the number of digital libraries, archives and repositories, which is largely due to the dissemination of various methods for the digitisation of analogue resources, and to the possibility of publishing their digital equivalents online. These possibilities have been exploited by numerous institutions with rich archival collections, including large scientific libraries being in possession of documents which, due to a poor physical condition, could not be made available [Kędziora and Góral 2010].

An important role in making cultural resources available via digital media is served by digital libraries. Almost every major cultural institution has such units. In line with their primary aim i.e. protecting and securing the cultural heritage, they are a platform of access to digitised contents [Buczyńska-Łaba and Krasińska 2016]. A modern library of the new millennium is perceived as an institution which, while performing its educational, cultural and social tasks, is not limited to informing about its own resources but becomes a centre of scientific and regional information [Marcinkiewicz 2010].

Online portals of digital libraries and repositories have become an informing, promoting, instructing and training tool. They provide a space for the exchange of communications and opinions between the library and the users through sending questions, opinions or demands via this channel. It is also a source of information on resources and services and a site of access to both electronic resources and to dispersed Internet resources [Wojnarowicz 2009].

Libraries actively participate in the protection of their regions' cultural heritage, and are a place where valuable regional collections are stored. In addition, they produce source materials such as regional bibliographies and databases [Janczulewicz 2016]. It is most common to create electronic archives from the resources owned by a particular institution [Kędziora and Góral 2010]. Another task of the library is to provide free access to the national and regional heritage of literary culture. This task can be performed using the potential of information technologies which enable the establishment of digital archives [Marcinkiewicz 2010].

A digital (electronic) archive is an information and documentation system aimed at the long-term protection of archival materials while using the latest achievements of digital technologies. The materials collected in a digital archive are described using metadata i.e. structured information which streamlines searching for objects in a database [Kędziora and Góral 2010].

In recent years, there has been a growing interest in the implementation of state-of-the-art technologies in the field of cultural heritage. Programmes have been developed that use information technologies to streamline documenting, protection and conservation of heritage, and to make resources available. Work is still underway to harmonise the standards of digitisation and archiving of virtual collections. As regards the numerous projects implemented to date, the particularly noteworthy ones are the studies demonstrating an increase in the efficiency and effectiveness of conservation operations, which results from the use of online databases [Kępczyńska-Walczak 2007].

Libraries implement numerous projects aimed at securing and making available historical collections for scientific and educational purposes. For example, the Library of the Jan Kochanowski University in Kielce has implemented a project aimed to process and digitise 19th century collections with, *inter alia*, the funds acquired from the Ministry of Science and Higher Education in Poland. The collection is the result of many years of efforts aimed at acquiring printed publications issued before the year 1901, securing them and making them available for scientific and educational purposes. The collection is comprised of 7,185 printed publications in Polish, Russian, German, French, English, Latin and Latvian languages. Formally, these include biographies, memoirs, correspondence, armorials, linguistic and thematic dictionaries, general and thematic encyclopaedias, bibliographies, diploma theses and legal documents. The collection also includes belles-lettres. The direct aim of the activities undertaken under the project was to secure valuable printed publications from the

19th century, and then to digitise them and make them available online. The most valuable of the digitised materials were introduced to the dLibra system, which made them available free of charge to an unlimited number of users. In this way, the security of these historic prints was enhanced as well, because the existence of a digital version prevents the need to make the original available. The collections are intended for researchers, teaching personnel and students as well as all people interested in the content or form of the publications. Under the project, 259 most valuable 19th century printed publications were digitised and made available on the Internet (50,000 scans). The documents were saved in a presentation format and introduced into the dLibra system. In addition, descriptions of these documents were sent to the Central Catalogue of Polish Scientific Libraries (NUKAT). In line with recommendations, a separate web page of the project has been developed and launched [Lubczyńska 2017]. Another example is the West Pomeranian Digital Library (ZBC Pomerania – Książnica Pomorska). The scope of collections subject to digitisation and making the digital versions available online includes: (1) cultural heritage resource (selected early examples of writing owned by scientific and public libraries in Szczecin and other libraries of the region), (2) regional resource – objects of Pomeranian origin of historical value – early examples of writing and social life documents including leaflets, exhibition catalogues, placards, posters, local government election campaign materials etc., iconography and music-related resources (score and literature associated with music), (3) science and teaching – PhD theses, habilitation theses, scientific articles, regional scientific journals, academic textbooks, textbooks making up the repository of West-Pomeranian libraries and universities, complete texts (from archival and modern resources) of local law provisions, resolutions of town/city councils, *poviats*, Zachodniopomorskie Voivodeship Sejmik (Regional Assembly), programmes, strategies, area development plans etc. (developed by the Municipal Office, Voivodeship Office, the Marshal's Office), information about regional economy, information bulletins of communes, towns and cities, *poviats* and offices, and local press [Marcinkiewicz 2010].

An example of a regional digital library that reflects the local resources located at the County Public Library in Sieradz is Digital Sieradz Land. The digital repository collects and makes available the cultural heritage of the Sieradz region (periodicals and social life documents) as well as regional publications collected by the well-known Sieradz chronicler and archivist Jan Matusiak. Digital Sieradz Land was established to protect from oblivion local periodicals and social life documents originating from the Sieradz region and thematically related to this area. On the initiative of the County Public Library, local periodicals with a low circulation were digitised. It should be borne in mind that these publications are not collected or stored by the National Library of Poland as they are not subject to the legal deposit requirement, which means that they may disappear irretrievably [Bartosik 2012].

Nowadays, in addition to institutionalised archives, there are numerous digital repositories established by specific institutions (museums, non-governmental organisations, scientific institutes), which digitise their collections and make them available on the Internet. One of them is a digital photography repository "Workers in the 19th and 20th century" with a collection compiled since 2012 at the University of Łódź in Poland as part of a project financed by the National Programme for the Development of the Humanities [Karpińska 2014].

4.4. Websites and social media

Nowadays, libraries and museums commonly use websites. According to the report "Museums in Poland", almost 93% of the total of 142 museums have a web page [Report 2016]. These websites differ in character and purpose, and are of various quality [Zachara 2016].

The electronic catalogue of objects of historical value on a museum facility's web page serves an informative role and may be an incentive to visit the museum. It does not compete with the objects exhibited at the museum but contributes to the enlivening of scientific work by enabling the exchange of information on historical objects between institutions specialising in various fields and located anywhere in the world [Zachara 2016]. Online catalogues of cultural heritage objects are usually established on the initiative of State institutions, local governments or other entities. They also result from enthusiasts' efforts. An example of an Internet cultural heritage catalogue is the online "Catalogue of monuments of Dutch colonisation in Poland" developed on the initiative of the Association of Historical Monuments & Art Conservators, the largest non-governmental organisation gathering the community of people professionally engaged in the protection of objects of historical value in Poland, and implemented with funds provided by the Ministry of Culture and National Heritage in Poland [Catalogue 2019]. The catalogue presents the history and evidence of Dutch colonisation in Poland; moreover, it serves to promote knowledge about this colonisation worldwide. The catalogue is intended to provide access to the documented forms of material cultural heritage associated with Dutch colonisation in Poland i.e. rural settlements, homesteads, residential and farm buildings as well as Protestant churches and cemeteries located so far in the regions of Pomerania, Mazovia, Podlasie, Lesser Poland, Greater Poland, Kuyavia or the Łęczyca Land, and to publically communicate the role played by the settlers in the history of Poland. The catalogue contains contents of a special nature that concern *inter alia* the characteristics of colonisation in Poland, the development of Dutch colonisation including the Mennonites, and the co-existence of nations and religions in Polish lands [Szałygin 2005].

Web pages serve a variety of functions in publically communicate the issues associated with cultural heritage. At the same time, they are used in the context of the recovery of cultural assets. Many websites of law enforcement agencies, cultural offices and institutions, sector organisations and foundations, mainly from Europe and the USA, are important sources of national and international information on works of art lost due to criminal activities as well as during the Nazi period (1933–1945). Because of the access to catalogues and databases, they are particularly useful for identifying lost objects and verifying the legal status of works of art in the course of trade [Lechowski 2005]. A national list of antiques that have been stolen or illegally transported abroad is available in Poland. This is an electronic base containing data on historical objects and works of art being searched for, available to all Internet users. The list is a useful tool for institutions engaged in the prosecution of crimes about objects of historical value, and is also used by institutions and natural persons to find out whether the historical objects being on sale are not obtained through criminal activity.

At this point, it is worth mentioning the Virtual Vellum project. Virtual Vellum is an e-science project aiming to promote and demonstrate the use of technologies in research in the field of arts and humanities [Blanke et al. 2009]. The project involved work on a tool that enables convenient online browsing of images with very high resolution, usually higher than 8k x 6k pixels, for example digitised manuscripts. In the first presentation of the tool, during a virtual workshop held in 2007, digitised manuscripts by Jean Froissart providing an account of the 100-year war between England and France in the 14th century were used [VV 2007]. Not only are these images interesting in historical terms but also extremely "fragile" and valuable; therefore, access to them is restricted [Blanke et al. 2009].

A challenge for people implementing the Virtual Vellum project was to provide instant access to large graphic files while maintaining a convenient browsing experience. High resolution of images was crucial as researchers are usually interested in details. The Virtual Vellum software makes use of data structures based on tiles and of the JPEG 2000 format. Along with the XML configuration files, JPEG 2000 can partially automate the tiling process. When using tiles, users do not need to view the entire image at once but only the appropriate tiles [Blanke and Hedges 2008, Blanke et al. 2009].

The 2010 Horizon Report: Museum Edition draws attention to the fact that social media offer an opportunity to reach new audiences and create communities centered around museum collections. It also enables a substantive discussion on the presented contents, and facilitates the learning process [Zachara 2016]. More and more Polish museums recognise the benefits of using social media. A statistical survey on this issue, conducted in 2014, showed that more than 80% of the surveyed museums in Poland used social media [Report 2016].

The development of digital technologies facilitates the activity of communities in collecting and sharing cultural heritage objects. Artifacts can be digitised, catalogued and archived, and tools such as web pages or applications have been developed to provide this information to users. This means that the objects of historical value that were only available in local library collections, cultural centres or private homes may now be made available to anyone with an Internet connection [Tait et al. 2013].

4.5. Geoinformation websites

Currently, we can observe a rapid development of various design techniques and tools, including API libraries, programming interfaces and frameworks which enable the creation of more or less advanced web applications. Their application, however, requires certain specialisation. At the same time, numerous wizards and generators are available that allow less advanced users to create components which extend website functionality. There are also many independent, ready-to-use components which only need to be adapted to specific requirements [Król 2018]. Selected tools can be used in the presentation of spatially referenced objects including historic objects.

Geoinformation websites enable the presentation of thematic contents against the background of various cartographic bases. The scope of their functionality may vary. These websites enable the presentation of thematic data including information on cultural heritage objects. The National Heritage Board of Poland mapping portal (mapy.zabytek.gov.pl) presents the objects entered into the register of historical objects, historic monuments and sites included in the UNESCO World Heritage List. The website database was established based on the reference data of the Land and Property Register (EGiB), the Land Parcel Identification System (LPIS) and the Topographic Object Database (BDOT). General geographic content is published using the resources made available by the Head Office of Land Surveying and Cartography or the Open Street Map [Bac-Bronowicz and Wojciechowska 2016]. Another example of a map website which makes available information on cultural heritage objects in spatial terms is the website "zabytek.pl". Among other things, it contains descriptions of historic monuments and objects of historical value, and galleries of contemporary and archival photographs. The resources include objects of historical value entered into the register of historical objects, historic monuments, archaeological sites and sites included in the UNESCO World Heritage List. Another geoportal which publically communicates cultural heritage issues is the Dolny Śląsk Geoportal (https://geoportal.dolnyslask.pl).

Many local geoportals that present cultural heritage objects operate on the Internet, for example a map of the Communal Register of Historical Objects in the City of Kalisz Municipal Spatial Information System (http://msip.kalisz.pl/msip/). This includes the areas under heritage conservator's protection, archaeological sites entered in the register of historical objects, and the objects and complexes included in the Communal Register of Historical Objects. It is worth stressing that the objects of historical value included in the Communal Register of Historical Objects have been entered into the address card system. Another portal that presents Polish historical objects is provided in the "Open Monuments" website established by the Centrum Cyfrowe Projekt: Polska (https://otwartezabytki.pl/). This is the Citizens' Catalogue of Historic Monuments based on the Register of Historic Monuments, that can be freely edited [Janus et al. 2014]. Another example is a database of industrial facilities, maintained by Historic England (formerly English Heritage). Historic England is a government agency which provides advice and consultation on all issues related to the conservation and protection of English architectural and cultural heritage [Skaldawski et al. 2011].

Another example is a database of architectural industrial heritage of the city of Wrocław, which can provide the basis for the establishment of Conservator's Sheets for historical objects, evaluation of heritage resources, and the public communication of knowledge on industrial facilities and their protection using geographical information systems (GIS) [Bac-Bronowicz and Wojciechowska 2016]. One more example is the online maps of cultural heritage that contain a specific inventory of cultural landscape objects [Opach 2012].

4.6. Mobile applications

More and more global sense of community and the decreasing access to heritage venues due to deterioration caused by "over-visiting" has raised an alarm to protect them by the implementation of pervasive computing applications at heritage sites and museums [Ch'ng 2011, Thwaites 2013].

Over the last dozen or so years, mobile devices have evolved from voice communication tools to mobile information systems using virtual reality technologies. The mobility of modern society has become a manifestation of contemporariness, and technological progress has become a catalyst for the development of mobile technologies that initiated the era of mobile communication. The number of mobile devices for which dedicated applications are the basic software is growing rapidly. They are finding more and more new applications, and provide both utility and purely ludic tools for establishing relationships with other users.

The widespread use of Internet-enabled mobile devices offers numerous new opportunities for commercial activities such as customer acquisition or targeted advertising. It also provides great opportunities to inform and educate inhabitants, local communities or tourists about historic monuments present in a particular location. Such opportunities are offered by mobile applications.

Applications for mobile devices are digital files designed to be used on modern electronic devices, in particular smartphones and tablets. They use image, sound, animation, augmented reality and geolocation, and combine them into a thematic whole [Zachara 2016]. An example of a mobile application which presents cultural heritage objects is a mobile app of the National Heritage Board of Poland called "Historic Monuments in Poland". The application "Historic Monuments in Poland" is the Institute's response to the growing interest in Polish historic monuments. The application is intended to encourage not only virtual but, primarily, active visits to historical objects. It provides information on more than 22.5 thousand historic monuments and objects of historical value. In addition, it uses resources of the "Wiki Lubi Zabytki" (*Wiki Likes Historic Monuments*) project maintained by the Wikimedia Polska Foundation which has been cooperating with the National Heritage Board of Poland since 2011. The application presents information on historic monuments located in the immediate vicinity using a GPS system. Moreover, historic monuments can be searched for by using a map that is a component of the application.

Another example is the applications provided by the Warsaw Uprising Museum. The Warsaw '44 – In the Footsteps of the Warsaw Uprising, an application implemented in 2011 contains information on 73 sites associated with the Uprising, *inter alia* the buildings of Prudential or the Polish Telephone Joint-Stock Company, or the entrance to the sewer at the Krasińscy Square. The sites and descriptions have been prepared on the basis of the "Przewodnik po Powstańczej Warszawie" (*A Guide to Insurgent Warsaw*) written by Jerzy S. Majewski and Tomasz Urzykowski. The archival photographs are part of the Warsaw Uprising Museum's collection. The application uses augmented reality (cooperation between a GPS receiver and a camera built into a mobile device with the database of the Uprising-related objects and information on them). Another mobile application "Pamięć miasta" ('*The City Memory*') was developed in 2014. It contains descriptions and photographs of the sites commemorating the insurgent combat (all these objects are placed on a virtual map). Another application called "Archimapa" is a multimedia bilingual guide to the architecture of Warsaw published in 2015, which presents seven issues associated with capital city architecture in the 20th century. All applications are available from online stores distributing mobile apps, and are free of charge [Zachara 2016].

4.7. Virtual museums, virtual tours and spherical panoramas

The presentation and promotion of digital collections of cultural heritage objects can be carried out using a web page that can provide a platform for various visualisation techniques [Pawleta 2016]. Technological progress, convergence processes and the development of visual communication encourage the establishment of new, alternative ways of presenting information. In recent years, the popularity of interactive visualisations has increased. The most popular forms of digital presentation of the reality (the space), made available as components of websites, include various interactive maps, charts and diagrams, infographics and multimedia materials including films and animations, and interactive visualisations e.g. panoramas or the so-called "virtual walks or tours". Interactive visualisations tend to take on an increasingly sophisticated form; they enhance the attractiveness of the message, and are successfully used to complement the written text.

It may appear that the cyberspace exists only seemingly and remains "dormant", "disabled" or "closed" on one of data carriers. Thanks to digital recording technology, it gains its reality at the moment when an application or a system is launched. Virtualisation of reality has allowed the functionality and usability of computer systems and applications to be extended.

Virtualisation is a process of creating such functions, tools or system components which are visible to the user of a computer (or another multimedia device) and fully functional but devoid of their original, physical basis. Virtuality denotes the digital character of the representation of any object or process, usually linked to its presence in the cyberspace [Pawłowski 2013]. Information virtualisation and visualisation are elements of the graphic design of media i.e. the art of combining communication goals of the message with the recipients' expectations.

Museums are interested in the digitisation of their collections not only for the sake of cultural heritage preservation but also to make them accessible in an attractive way. New technologies such as virtual reality (VR), augmented reality (AR) or Web3D are commonly used to establish virtual museum exhibitions both in the museum environment e.g. via information kiosks, and on the Internet [Styliani et al. 2009].

Virtual reality is a reflection of the real world, the transformation of physical objects to a digital form using computer techniques. The virtual world is an interactive, computer-generated, three-dimensional environment that can be either static or dynamic [Berbek 2016]. It is generated in a process of virtualisation i.e. digitisation, processing, transfer of activities and objects to the virtual space and their further distribution with the use of computer networks [Mazurek 2012]. The virtual reality is characterised by immateriality, interactivity and the "immersion potential" that creates an impression of a "transition" to another environment. Most frequently, such a transition is facilitated by software and hardware that generate a (three-dimensional) image, and multi-sensory sensations [Kieszek 2016]. Moreover, the augmented reality i.e. a system that links the real world with the computer-generated one has more and more applications. For example, Google Street View allows one to travel the length and breadth of the virtual space, and explore cultural heritage objects.

Virtual reality and virtualisation are now successfully applied for the presentation of cultural heritage objects. Digital repositories of museum collections made available online in the form of virtual museums, virtual tours and electronic catalogues of museum exhibits with extended visual and informational content are becoming increasingly popular. A virtual exhibition is a form of digital presentation of historical objects combined into collections i.e. exhibitions, also related to as present in "galleries". The attraction of virtual exhibitions is the historic monuments presented in the 3D technology which allows the visitor to get a close look at the faithful representation of a particular object. What is also worth stressing is the possibility for a multiple blow-up of an entire historic monument or its part on the screen. This function is particularly appreciated by scientists, hobbyists and the visually impaired [Zachara 2016].

A virtual museum is a logically selected collection of digital objects made using a variety of media techniques. Thanks to their compatibility and numerous forms of access, such collections go beyond the traditional forms of communication and interaction with the visitors, can be adjusted to their needs, and are generally accessible [Pawłowska and Matoga 2014]. Virtual museums are institutions whose exhibits (or interiors and exhibits) are on public display via electronic means. These are "stand-alone" museums, which means that they only exist on the Internet or are complementary to the real (stationary) museums [Stefanik and Kamel 2013].

Online virtual museums are addressed to everyone, and are intended to encourage them to visit the real museum. People who, for various reasons, cannot come to the museum, are offered an opportunity to experience historic monuments e.g. in the form of a high-resolution photo gallery [Zachara 2016]. Projects of this type include four main elements, namely information on the museum, presentations of the most important works of art, a virtual tour of interiors, and three-dimensional graphics [Gontar 2013]. Therefore, virtual museums are a generally accessible, interactive collection of 3D reproductions or copies of historical objects, generated with the use of computer methods [Bentkowska-Kafel 2013]. The very process of digitising museum collections, which *inter alia* results in the establishment of virtual exhibitions or museums, contributes to the dissemination of knowledge about cultural resources [Gontar 2013].

Virtual museums using digital reproductions may serve functions of a traditional museum e.g. archiving, exhibit protection and education [Pawłowska and

Matoga 2014]. Moreover, they use modern forms of communication including virtual tours, spherical panoramas and three-dimensional visualisations which are often accompanied by sound effects. Virtual tours have the same interactivity characteristics as spherical panoramas; however, in contrast to them, they enable travelling through the virtual space that is "frozen in time", of course to the extent to which it has been digitised [Król 2018]. Virtual museums make cultural heritage objects appear to be accessible almost "at one's fingertips" without leaving one's home.

An example of the use of three-dimensional visualisations in the preservation and promotion of cultural heritage is the virtual model of selected localities of the Lublin Region. Traditional wooden building is becoming a thing of the past, as most houses have burnt down or been destroyed during armed conflicts. The remaining ones were dismantled in the post-war years of the 20th century. Windmills, watermills, smithies, inns, and wooden buildings in rural farmsteads are very rare nowadays. However, each such preserved structure is a testimony to traditional wooden architecture as well as a source of information on customs, culture and history. The project "Wooden Treasure. By Protecting Heritage We Create the Future" was aimed to document and promote traditional wooden architecture of towns in the Lublin region, and to sensitise local communities to the problem of degradation of the multicultural heritage of the Lublin region. Nowadays, historical 3D models of towns covered by the project which are available online are among the most effective ways of telling stories about cultural heritage. One of the project outcomes is the virtual models of Krasnobród, Tyszowce, Szczebrzeszyn, Wojsławice and Dubienka, which represent the space of small towns in the interwar period of the 20th century, and a model of Larvik (a Norwegian town and municipality in the region of Vestfold) in three historical periods: in 1690, 1777 and 1900 [Kowalczyk et al. 2015].

4.8. Photogrammetry and 3D modelling

One of the most important means for transmitting cultural heritage to posterity is sensitive documentation [Yilmaz et al. 2007]. Thorough documentation of cultural heritage status is essential for its protection and scientific research carried out during the restoration and renovation process. Photogrammetry has long been used as a tool for collecting three-dimensional (3D) information of cultural heritage objects as well as texture information. Nowadays, terrestrial laser scanning systems are very popular and used for the documentation of cultural heritage as well as modelling and 3D visualisation [Yastikli 2007]. The digitisation of cultural assets, including the construction of three-dimensional models of objects, landmarks and cultural heritage sites, is one of the key challenges in the context of their protection. In all the branches of the cultural heritage field, the 3D survey is an essential support for a number of activities: the object documentation, different kinds of analysis, the communication and promotion of the sites, and so on. The possibility to generate accurate and detailed 3D models from imagery is a great opportunity with limited costs. Virtual modelling and 3D reconstruction are commonly used in the field of cultural heritage to reconstruct, analyse and visualise both large objects e.g. archaeological sites and architectural structures and small objects such as sculptures or jewelry [Portalés et al. 2009].

Currently it is possible to apply a variety of technologies to obtain realistic 3D models. On the one hand, accurately modelling the existing 3D data is sometimes complicated and costly since the "reality" is complex: the more complex the object, the more complex the model. On the other hand, models are often constructed in order to visualise the condition of historic monuments that are not fully preserved. In this sense, "augmented reality" technology may serve an important role in the protection of cultural heritage [Portalés et al. 2009].

There are several proven methods of 3D modelling e.g. image-based methods that exploit photogrammetric aspects in creating high fidelity 3D maps, photometric stereo that exploits light reflection properties for 3D modeling, real-time depth sensors to create cost-effective but low fidelity RGBD images, structured light technologies with the capability of simultaneously capturing 3D geometry and texture, and laser scanning for large-scale automated 3D reconstruction [Voulodimos et al. 2016]. Terrestrial laser scanning, photogrammetry and tacheometry data have been successfully used for years for recording of cultural heritage buildings [Grussenmeyer et al. 2008]. Multi-image photogrammetry is a practical tool for cultural heritage survey and community engagement [McCarthy 2014]. Structure from motion (SfM) photogrammetry is used to reproduce cultural heritage sites in virtual reality (VR). The unique texture of heritage places makes them ideal for full photogrammetric capture. An optimized model is created from the photogrammetric data so that it is small enough to render in a real-time environment. Creating these experiences can bring people to cultural heritage that is either endangered or too remote for some people to access [Dhanda et al. 2019].

Photogrammetry (PH) is the art and science of determining the position and shape of objects from photographs. Computer Vision (CV) is a mathematical technique for recovering the three-dimensional shape and appearance of objects in imagery [Szeliski 2010]. Photogrammetry and Computer Vision – both these techniques start from the analysis of 2D images to discover 3D shape information, even if the employed approach is sometimes different: originally, the goal of PH was the measurement of the position of a set of 3D points, while CV aimed at the final appearance of the model [Aicardi et al. 2018].

One of the first stages of the protection of cultural heritage elements is its identification and description which, under specific conditions, can be referred to as an inventory. The inventory of urban architectural complexes, greenery complexes and architectural structures in Poland is the subject of the Technical Guidelines G-3.4 developed in 1981 by the Head Office of Land Surveying and Cartography [Technical Guidelines G-3.4]. In accordance with the Guidelines' provisions, an inventory involves imaging of the existing spatial condition, the functional and technical structure, and the design of objects. In order to draw up complete documentation, the information that presents the current state of a building, including the views of the elevation and interiors, is required *inter alia* to be collected. Documentation drawn up in many stages is the basis for undertaking research, design or technical work that enables the protection of objects against destruction, their adaptation to serving specific functions, or restoration.

The inventory can be considered in a dual context: as an urban inventory whose task is to present the existing spatial arrangement, including the identification of the technical and functional structure as well as the interior furnishings, and as an architectural inventory that involves the representation of the actual bodies of objects based on measurements (Fig. 15). The architectural inventory addresses buildings of masonry and wooden architecture, interior design objects, architectural design details and landscape structures.

A traditionally implemented inventory process comprises two stages. The first of them involves field works aimed at obtaining photographic documentation, the performance of an accurate survey, and describing the object under inventory. The second stage involves in-house work.

The descriptive part of architectural inventory comprises technical development along with the location, a description of the object type and character, the number of stories for buildings, the height, the area, and a description of materials from which particular elements are made.

Views, projections and cross-sections are traditional, analogue forms of the metric documentation of historic monuments. They have been presented in a variety of scales, with views also as analogue rectified mosaics in the form of photographic documentation [Werner et al. 2014].

With the development of computer techniques, analogue forms of description have been replaced with the digital form, initially recorded in the form of raster files, and then of vector files [Piszczek et al. 2008]. For several years i.e. since the moment when software that enables the vector-based preparation of documentation became available, the results of a survey imaging the architectural inventory may be stored as files in formats native to the programs CAD or Adobe Illustrator. However, digital storage entails the risk of losing files due to a change in the storage technology, the replacement of reproduction programs, etc.

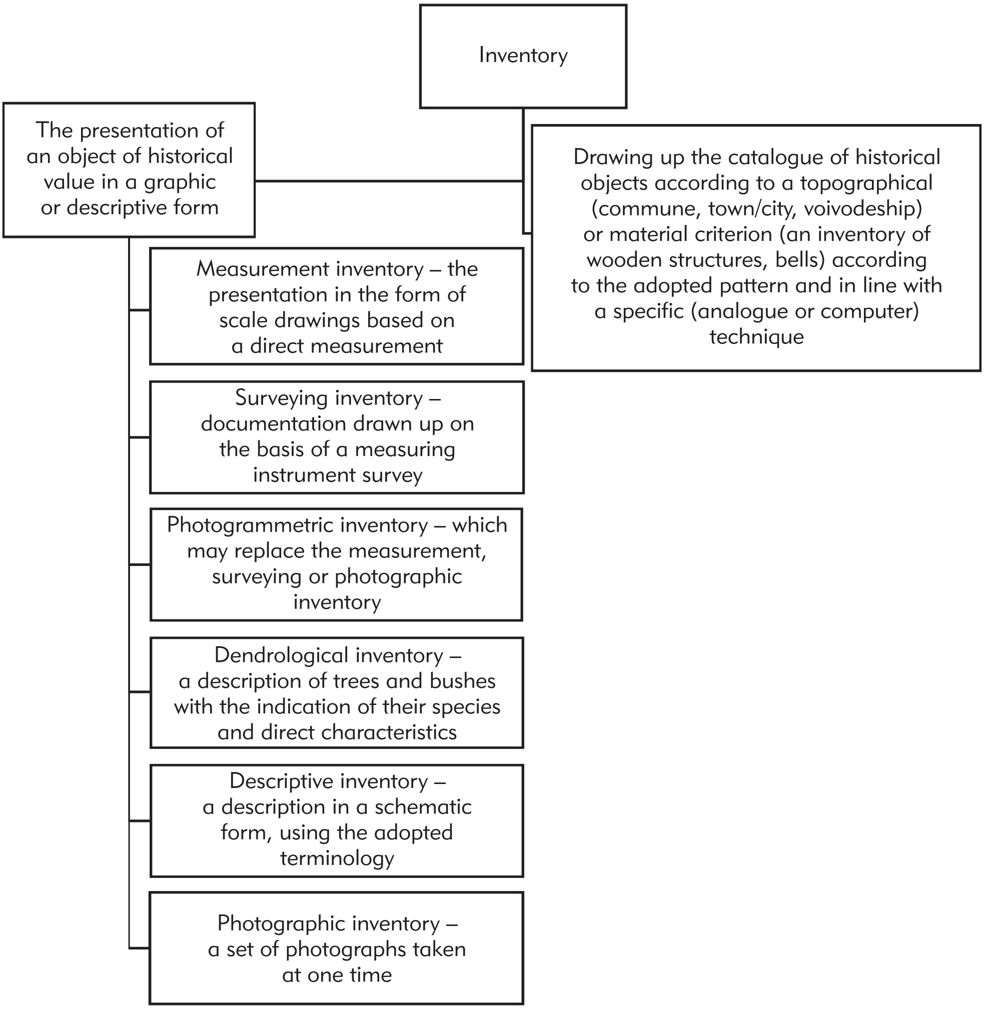

Fig. 15. A diagram of the process of historical object inventory

Source: Authors' own study

Computer methods enabled the development of modern forms of documentation characterised by a high level of accuracy, and taking into account the smallest details. Classical inventories carried out by direct geodetic survey methods e.g. the method of polar coordinates, orthogonal method, angular and linear intersection methods or photogrammetric methods involving the processing of individual photographs and the development of stereograms using photogrammetric stations, have been driven out by modern surveying methods including, increasingly often, by laser scanning technology.

Taking into account photogrammetric methods, a photogrammetric digital station enables the performance of surveys and stereoscopic vectorisation, the development of a tuned 3D model, and the processing of digital images by the orthophoto method. There are two methods of photogrammetric studies: single- and double-image. The selection of an appropriate method is determined by the geometrical form of an object. Where the object under inventory is flat and can be approximated with a slight approximation using a plane, the single-image method is applied [Smirnowa 2016]. In the inventory of historic buildings, flat elements are wall paintings and the spatially non-extended building elevations (e.g. with no cornices or balconies). The main principle of the method is that the survey photographs need to be taken approximately parallel to the plane of the object, and that the camera needs to be located at an appropriate distance. The longer the distance between the camera and the object, the smaller radial deviations on the image are, and thus the study accuracy increases. According to the G-3.4 instructions, a field accuracy ranging from 1 to 2 cm was assumed for these types of studies [Technical Guidelines G-3.4]. Documentation of a wall painting inventory should be more accurate (a few millimetres) due to the smaller dimensions. In the single-image method, survey photographs are taken using large-format, analogue photogrammetric cameras and digital cameras with a lens without radial distortion.

Objects with a more complicated design need to be processed based on stereograms i.e. pairs of stereoscopic photographs. In such a case, to make an inventory of extended objects that contain multiple architectural details, the double-image method in which the location of points is determined based on intersection is applied. This enables the removal of the effect of radial deviation of homologous points of both photographs on the final accurate result. A survey photograph is taken from two points i.e. from the so-called photogrammetric base. In the double-image method, the principle determining the study accuracy applies as well. The greater length of the base and the scale of the object in the photograph, the higher the accuracy. This method is applied in the inventory of paintings located on expandable surfaces (barrel vaults). In such a case, stereograms provide the basis for the preparation of the view extension rectified mosaic, and provide information on the vault geometry [Boroń et al. 2007].

The performance of photogrammetric inventory by both the single- and double-image method requires the establishment and measurement of a network, taking survey photographs, in-house work involving the drawing up of digital inventory documentation, and the archiving and printing of the digital documentation.

The development of land-surveying techniques enabled the introduction of thermographic testing to inventory technologies as early as the 1970’s, while detailed laser images enabling detailed reconstruction of historic objects were introduced in the 1990's. Ground-based laser scanning enabled a thorough inventory of historic objects and an analysis of the state of their preservation as well as, in the longer term, the determination of the degree of damage caused by external factors.

In the 1970's, an attempt was made to use thermal imaging for the conservator's examination of historic architectural structures [Gala 1975]. Thermal imaging surveys are based on the physical phenomenon of emitting electromagnetic waves by each body with a temperature higher than absolute zero. In terms of the wavelength, this radiation is referred to as infrared radiation, while in terms of the properties it is called thermal radiation. The intensity of thermal radiation is fully proportional to the object temperature [Hulewicz 2017]. Thermal imaging is a research method that involves a remote, non-contact analysis of the temperature distribution over the surface of the item being tested. A thermal imaging apparatus is a variant of television sensitive to a section of the infrared radiation range. An image is created by means of recording the radiation emitted by the observed object using a camera, followed by its conversion into a colourful temperature map. Testing of this type is used *inter alia* for non-invasive tests on the structure of buildings, the estimation of heat losses, the detection of defects in thermal insulation and the location of moisture contamination areas, the examination of phenomena associated with the physics of buildings i.e. freezing, swelling, water vapour condensation, drawing up the documentation of the distribution of object surface temperatures depending on the degree of solar exposure, the time of the day and the season.

Acquiring data by means of a laser scanning technique involves the determination of the spatial location of elements describing the exact geometry of the object being surveyed, and the assignment of radiometric values on a grey scale i.e. the so-called artificial colour palette or colours in the form of RGB components [Boroń et al. 2007]. Laser scanning is a measurement method that involves the transfer of an actual three-dimensional shape of objects to a digital form. It enables the measurement of structures and architectural details with high speed and accuracy.

The literature provides no clear definition of laser scanners; in practice, however, they are regarded to be instruments which quickly obtain spatial data in the form of sets of points with known XYH coordinates of the designated area of the object surface being measured, regardless of the technique, the manner of work and the method for determining these coordinates. Sets of points with spatial coordinates of the area under inventory within a specified system are designated automatically i.e. without human intervention during the measurement, with high speed (from several hundred to several thousand points measured within 1 s). A 3D point cloud is obtained in real time as the measurement result.

The first-ever scanner was constructed by Ben Kacyra at the beginning of the 1990's [Wężyk 2006]. Kacyra had repeatedly struggled with the problem of inventory of civil structures and with the precise reconstruction of the location of "critical" points of the structure design. It was then that the idea of replacing a measuring tape with a new technology was born. In 1993, Kacyra founded the company Cyra Technologies in order to improve this technology with his partner. Lasers were already in use. Barcode readers and laser printers were emerging. In the measurements that Kacyra had in mind, a beam of light should reach a distance of several hundred meters, be safe for humans and record thousands of points with a millimetre accuracy within a second. To implement the project, it was necessary to use a laser located at the Massachusetts Institute of Technology. Cyra Technologies obtained a civil licence for the use of the invention, which enabled the construction of the scanner prototype. The first test of the AlphaCyrax scanner was conducted at the Chevron refinery in Richmond.

Besides Cyra Technologies, the Los Alamos National Laboratory and the Lincoln Laboratory also participated in the scanner construction. The complicated process of constructing the instrument involved many scientists. Physicists from Los Alamos were responsible for designing an integrated circuit for precise time measurement, and the Lincoln Laboratory scientists' task was to produce a high-class laser. Cyra undertook to create graphics and CAD software, and to connect the software with the laser and the rest of the device.

The key element of the scanner was the electronic system responsible for sending the laser beam within an appropriate time interval, and for measuring the return time of the pulse reflected from the object. In 1994, the signal-generating system was already ready, and the first commercial model was released by Cyra Technologies in 1998. The first manufactured devices scanned within a range of 40° over a distance of 100 metres with an accuracy of 2 millimetres. Moreover, the first scanner differed from those currently used in external design and size.

Nowadays, the laser scanning technology enables the active inventory that allows data about an object to be obtained. Additionally, besides the traditional forms of documentation, three-dimensional reconstruction of the object is possible. Generating a spatial model has many advantages: various measurements can be carried out on a model, and the projections and cross-sections are generated automatically. Each model can also be assigned with a natural texture derived from photographs taken using a scanner.

4.9. Destruction in the preservation of cultural heritage

In the theories of cultural heritage conservation, new concepts and tendencies have been emerging, including: (1) recognising that the reversal of time is impossible (acceptance of progressive changes); (2) perceiving destruction as an integral part of heritage; (3) positive valuation of the multiculturality and multiethnicity of heritage; (4) not leaving heritage protection in the hands of experts alone, and, in particular, the management of heritage in cooperation with the native inhabitants of the region, and (5) regarding the protection as an activity carried out for the benefit of the present and the future [Lowenthal 2000].

In the context of digital artifact preservation and protection, it is the concepts of perceiving destruction as an integral part of heritage and of not leaving the heritage protection in the hands of experts alone that are particularly significant. In certain cases, the preservation of integrity of a historic object is not the most important principle determining the actions to be taken in relation to a historic monument or an object of historical value. This justifies data migration as one of the ways to save digital artifacts, even though the migration process may contribute to a change in the object. The preservation of a digital artifact may require the replacement of its authentic substance; in a conscious and controlled manner, the old substance is completely removed and replaced with a material trace only. When emulation comes to nothing, no data migration is possible or the original equipment is lacking, a way to preserve software may be the recording of the process of its use e.g. in the form of a video material, extended to include documentation providing information on the artifact i.e. what it was, what it is now and how it operates [Newman 2012a]. In selected cases, digitisation may be of help as well.

Chapter 5

Technological Museum

A computer is a machine with a soul, and it must be kept alive with its operating environment to show its abilities and the contemporary state of the art [Burnet and Supnik 1996, p. 33]. For years, the communities involved in digital archiving and the protection of digital resources underestimated the point that a good way to preserve archaic digital objects is to preserve obsolete computers. It is migration and emulation that were perceived as the main ways to keep software and files usable. This, however, can be particularly difficult for digital materials generated in the mid-1980's. This is a set that comprises a number of incompatible operating systems, file formats and multimedia formats which ceased to be used and were replaced with other, more efficient ones, while their creators did not care to preserve the memory of them or to pass on what they had created to subsequent generations. To understand the specificity of these contents, it is often necessary to get to know and to preserve the digital ecology of the functioning systems i.e. operating systems, peripheral device controllers, communication protocols and machine specifications [Galloway 2011].

Retro-computing is not a new phenomenon. Users have always collected computers for various reasons, and it is not limited to hardware itself. Software, which often has been written by the users themselves, is collected as well. Enthusiasts still maintain and make available online compendia of a wide range of software developed for the early machines by afficionados. Consequently, there is still a considerable collection of historical and documentation materials concerning early microcomputers from the 1970's and '80's, and a large number of enthusiasts who collect the materials and work using them because of their own passions and interests [Galloway 2011].

Technological Museum is an institution, community or a person that collects and maintains the original hardware and software used to establish or gain access to digital materials. This approach to the preservation of digital artifacts focuses on maintaining hardware and software for a longer time i.e. providing the original environment for specific software [Pearson and del Pozo 2009]. The original hardware and software may offer the only opportunity to read certain digital materials, and ensure the originality of the experience of the use. The hardware requires maintenance and considerable knowledge of the preserved systems. The older the hardware, the more difficult and costly it is to find an appropriate substitute or to repair it. In addition, older equipment may become increasingly dangerous over time due to e.g. the chemical component decomposition or an electrical failure.

It is possible and effective to maintain the original software and hardware for machines built from standard components. As regards programs that need an original data carrier to be launched, it may appear that preserving the original hardware will be the only effective way to preserve digital museum objects [Guttenbrunner et al. 2010].

Selected digital machines have gone down in the history of computerisation, and been a milestone in the development of computer mobile devices that are used nowadays. This is showed by, for example, the history of the digital machine ENIAC in the United States, of the series of British ICL computers, or the machine ODRA in Poland.

5.1. ENIAC: a robot mathematician and its mechanical brain

It is assumed that the first practical, fully electronic computer was presented on 14 February 1946 at the University of Pennsylvania (USA). The people responsible for its success are primarily J. Presper Eckert and John W. Mauchly [Randall 2006].

Hailed by The New York Times as "an amazing machine, which applies electronic speeds for the first time to mathematical tasks hitherto too difficult and cumbersome for solution", ENIAC (Electronic Numerical Integrator and Computer" was revolutionary for its time [ENIAC at Penn Engineering 2019].

While ENIAC was commonly regarded as the world's first computer until 1975, the British machine Colossus and the ABC (Atanasoff-Berry Computer) computer constructed in the years 1937–1942 at the Iowa State University by John Vincent Atanasoff and Clifford Berry (Fig. 16) also compete for this title.

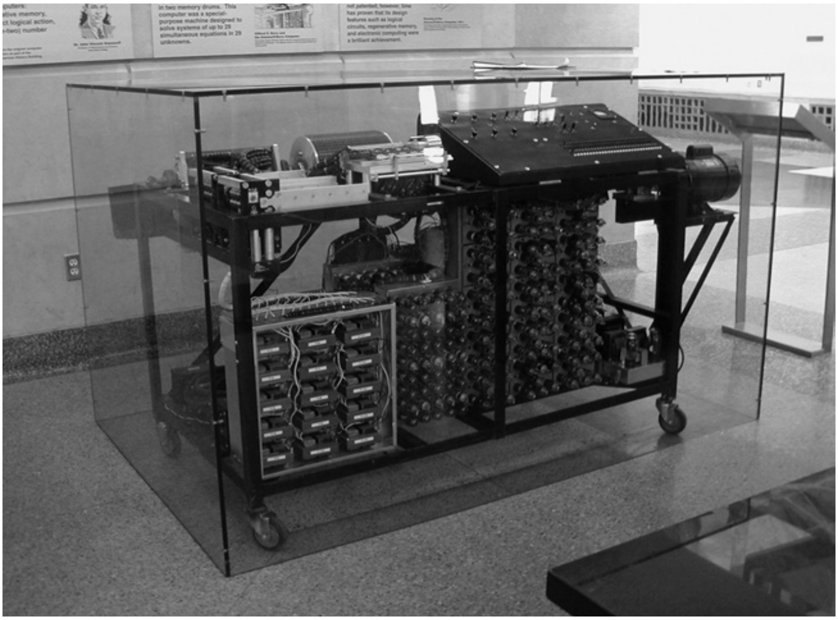

Fig. 16. The Atanasoff-Berry Computer at the Durhum Center, Iowa State University
Licence: CC BY-SA 3.0
Source: pl.m.wikipedia.org

In 1946, Tadeusz Unkiewicz, a populariser of science, the founder, editor-in-chief and publisher of the "Problemy" monthly, was astonished that "there is not a single moving part" in the electronic computing machine ENIAC. At that time, he used the phrase: "a robot mathematician who works with the speed of light and radio waves". A few decades ago, despite its weight of 30 tonnes, ENIAC was the "peak of precision and subtlety" [Unkiewicz 1946].

ENIAC is a general-purpose computer machine developed by the Moore School of Electrical Engineering (University of Pennsylvania, Philadelphia) for the purposes of the Army Ordnance Department, U.S. Army. The primary machine's task was to carry out calculations related to ballistics i.e. to calculate firing tables for the armed forces. (Numerical) firing tables are the basis for calculations carried out during the control of a gun, and are a set of the bullet's flight path coordinates. According to Bogdan Miś [1996], it took from 1000 to 2000 hours of calculations i.e. from 6 to 12 weeks of work to prepare a typical firing table, while the armed forces needed tens of thousands of such tables as it was the time of the Second World War. The calculations required for the preparation of the tables were so complex and time-consuming that they exceeded the capabilities of computing machines of the time, particularly for weapons under development. For this reason, the U.S. War Department decided to fund the ENIAC project [Hartree 1946, Polachek 1997]. What is more, the ENIAC design enabled the solution of various numerical problems that were too difficult to solve using more conventional (at that time) computational tools.

5.1.1. As fast as ENIAC

The basic computing element in the ENIAC machine was the electron tube. This helped ENIAC operate much faster than the calculating machines constructed on the basis of electromechanical relays which performed only a few operations per second [Hartree 1946, Marczyński 1954]. To ensure easy and accurate computations, ENIAC was designed as a digital device. The equipment usually supported signed 10-digit numbers expressed in the decimal system. It was, however, designed in such a way that operations with 20 digits were possible. Besides ballistics, ENIAC's fields of application included weather forecasting, atomic energy calculations, cosmic radiation testing, designing wind tunnels and other scientific applications [ENIAC at Penn Engineering 2019]. ENIAC could add two 10-digit numbers in 0.0002 seconds, which is 50,000 times faster than a human, 20,000 times faster than a calculator, and 1,500 times faster than Mark I (IBM Automatic Sequence Controlled Calculator) [Randall 2006]. With the use of ENIAC, ballistic calculations which had previously been carried out for approximately12 hours using a hand-held calculator took only 30 seconds [ENIAC at Penn Engineering 2019]. The computations themselves were therefore performed very quickly, but the main difficulty was that ENIAC did not enable the storage of programs. In order to solve each new problem, it was required that the machine be reconfigured in a tedious way, which lasted for up to two days. The program was set by manually connecting cables and properly configuring switches linked to different components of the computer [Randall 2006].

All instructions needed to perform computations were fed into ENIAC prior to the commencement of computations – "All data and instructions required by the machine at any time during computations had to be entered onto functional sheets before the work was commenced. Changing the program took a long time due to the need to switch a lot of contacts, commutators and connections. Errors made while setting the machine resulted in many delays and jammings. It should also be mentioned that the electronics of that time caused additional problems, as the average time of the failure-free operation of a machine amounted to approximately half an hour" [Miś 1996].

ENIAC had a modular design and an impressive size. The machine was comprised of forty-two black steel sheet cabinets with a total weight of approx. 30 tonnes, which covered an area of 72 m² [Sienkiewicz 2006]. Each "cabinet" was 3 m high, 60 cm wide and 30 cm deep. The ENIAC computing module comprised 40 panels which contained a total of approximately 18,000 vacuum tubes, 1500 relays and 50,000 resistors. ENIAC circuits included 500,000 soldered connections, 70,000 resistors and 10,000 capacitors (Fig. 17).

ENIAC panels were grouped into 30 units, with 20 of them performing mainly arithmetic operations. Moreover, ENIAC also had its own dedicated power lines and used 150 kilowatts of electricity [ENIAC at Penn Engineering 2019]. ENIAC performed the operations of adding, subtracting, multiplying, dividing, squaring and automatic searching for function values [Burks 1947]. Moreover, ENIAC could solve three-dimensional second-order differential equations [Randall 2006].

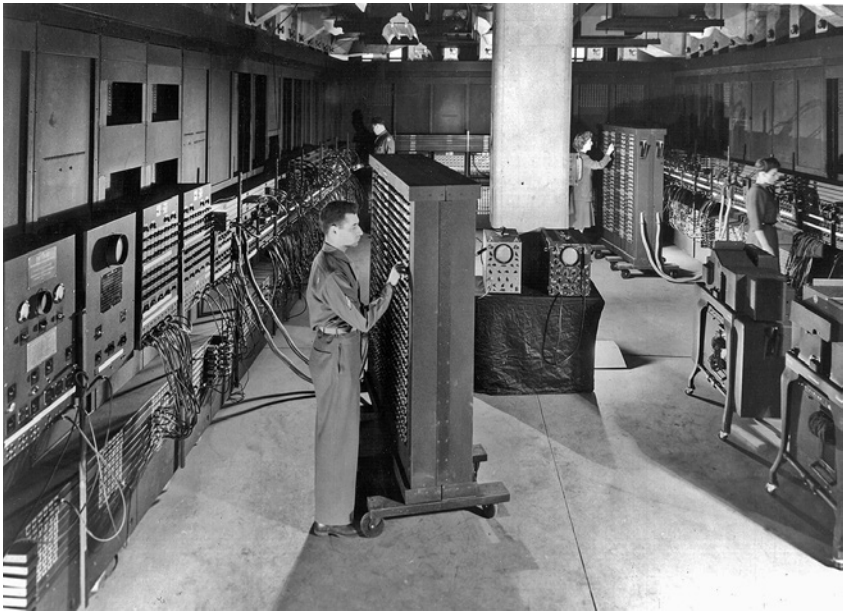

Fig. 17. The classic shot of ENIAC while still at the Moore School. Soldier at foreground function table: CPL Irwin Goldstine
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5.1.2. The ENIAC heritage

The original Edison's light bulb does not resemble a modern bulb; it serves the same function but is constructed of completely different components. The same is true of computers. Thus it is the concepts and not the hardware that have survived [Randall 2006]. As the computer technology was evolving, ENIAC had become obsolete. When ENIAC's utility decreased, in October 1955 at 11:45 PM it was removed from service, and the U.S. government decided to scrap it [Richey 2019]. After the users' protests, parts of the machine were successfully saved. Four out of the original 40 ENIAC panels represent approximately one tenth of the machine's initial size, and are currently located at the School of Engineering and Applied Science (University of Pennsylvania, Philadelphia, USA) [ENIAC at Penn Engineering 2019].

Relics are all that has remained from this powerful machine. They serve as a permanent exhibition in the same room at the Moore School of Electrical Engineering (University of Pennsylvania). The history of ENIAC is documented by a large, black, cabinet-like panel with a digital display unit which looks like several fiscal cash registers stacked on top of each other. A metal box called a battery, with several rows of knobs and switches, is located on one side of the cabinet. On the nearby table, several "trays" with rows of glass vacuum tubes are located. For the scientists who constructed ENIAC, the modest presentation evokes vivid memories.

5.2. ODRA: introduction to the history of Polish computer thought

The second half of the 20th century provided the world with the rapid development of computer science, which continues to this day. Poland has made, and is still making a considerable contribution to this development. In January 1970, the first public demonstration of program compatibility between ODRA 1304 and the ICL 1904 computer was held at the Electronic Computational Technique Plant ZETO in Wrocław. The results and the operator's messages were then found to be compatible. The Polish Committee for Mathematical Machine Assessment confirmed the full acceptance of the ICT-1900 series software on the ODRA 1304 machine constructed at the Polish ELWRO plant. The exhibition enjoyed success. However, could the world at that time allow Poland to become the centre of development of computer thought? The ODRA 1300-series processors with system software proved to be so good that it caused astonishment on the British side and hostile responses on the part of Moscow. The authorities in Moscow pressed the Polish side for a long time and severely to cease the manufacture of ODRA which was much better than the Soviet computer systems of the RIAD series. The success of the ODRA computer presentation turned out to be fraught with consequences. Soon afterwards, the only Western company that manufactured special interface cables for the ICL 1900 machines i.e. for the ODRA machine as well informed the ELWRO's sales department that it was ceasing their production due to technical reasons. Interestingly, when the cables were acquired with great difficulty, and the production of ODRA was resumed, the company concerned resumed the manufacture of cables that had been ceased allegedly "for technological reasons".

Despite the design successes, at the end of the 1970's the ODRA computers manufactured in Wrocław had to give way to Soviet machines of the RIAD series, significantly less advanced and useful as compared with the ODRA digital machines, that were imposed by the Council for Mutual Economic Assistance i.e. an organisation established in Moscow in 1949 to coordinate economic cooperation between the states subordinated to the USSR. However, even though the ODRA 1305 was not "politically correct" for reasons beyond the control of ELWRO, its production was continued until 1986, and in the military version (as the RODAN 15) until 1991. The last ODRA 1305 system was shut down in 2010. This story, which is very briefly presented, is part of our common heritage, not only digital but cultural heritage in general. Let it serve as an introduction to further considerations concerning the protection and preservation of digital cultural heritage objects as well as making them available.

It is assumed that the era of computers was already initiated in Poland at the end of 1948 when the Group of Mathematical Apparatuses was established at the Institute of Mathematics in Warszawa. The first analogue computer known as the Analyser of Differential Equations was completed in 1954 and used for a few years [Madey i Sysło 2000]: "with its help, it was possible to solve systems of up to eight ordinary differential equations of the first order. The equation parameters were changed using knobs, and the effect could be observed on several display units." The first successful digital computer, or rather an electronic digital machine, as it was then called, namely the XYZ, was completed in 1958. The XYZ digital machine performed approximately 800 operations per second, and was a milestone in the development of Polish computers. Shortly afterwards, the XYZ computer was upgraded and, under the name of ZAM 2, was manufactured and installed in many locations both in the country and worldwide [Lukaszewicz 1990].

On 6 February 1959, a State-owned enterprise Wrocławskie Zakłady Elektroniczne ELWRO was established (Fig. 18). This is where the legend of Polish computer science, namely the Odra computer, came into being [Nowakowski 2019]. The concept of a digital machine family ZAM (ZAM 11, ZAM 21, ZAM 31, ZAM 41 i ZAM 51) was formulated in 1965. It was another, after the IBM, concept of a series of computers with increasing utility features [Bilski et al. 2017].

A Resolution of the 7th Convention of the Polish United Workers' Party (8–12 December 1975) very strongly emphasised the development of automation in the years 1976-80. At that time, the potential of computerisation that was to determine an increase in work efficiency was already noticed. Computerisation

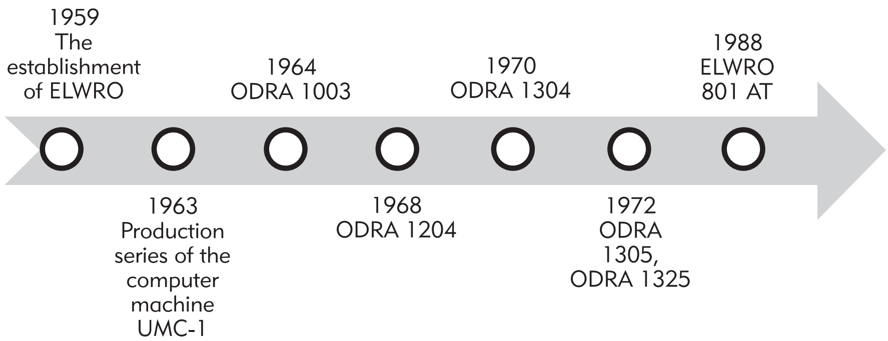

Fig. 18. Evolution of the ODRA computer series, part 1

Source: Authors' own study based on ELWRO [1989]

was supposed to bring about tangible and concrete effects. In the years 1976–80, Wrocławskie Zakłady Elektroniczne "MERA-ELWRO" began to serve as the general supplier of computer systems [Mera-Elwro 1975].

5.2.1. ODRA: the first- and second-generation computers

The ODRA 1001 machine constructed on the basis of vacuum tube technology (the first generation) was launched in June 1961. One of the design challenges was to build a memory drum with a capacity of 1024 words. The memory module was comprised of a cylinder placed in an appropriate casing which was to rotate at a speed of approximately 3,000 revolutions per minute. In the upper part of the casing, bus bars were located on which 64 read-write heads were installed. The heads were placed above the track, each containing 32 18-bit words. The drum was perfectly balanced and covered with a ferromagnetic layer which allowed information to be recorded digitally [Zuber 2015]. At the same time, technical assumptions were developed for the ODRA 1002 machine (Fig. 19) based on vacuum tube and transistor technology (the first generation) with higher technical parameters; (a specimen of this machine is exhibited at the Museum of Technology in Warsaw). The assembly of the ODRA 1002 machine was completed in December 1961, and in June of the next year it was launched (Fig. 20). Neither ODRA 1001 nor ODRA 1002 went to serial production due to relatively high failure frequency [Maćkowiak et al. 2018].

ODRA machines were referred to as a "computer family". However, this can only be understood figuratively as they indeed had a common genealogy while not being compatible; not only did they differ in technical implementation and logical organisation but primarily in architecture. A real machine family was only formed by the ODRA 1300 series models manufactured from 1970 [Komorowski 2002]. It appears that the basic factor affecting the conception of these machines

Fig. 19. ODRA 1002

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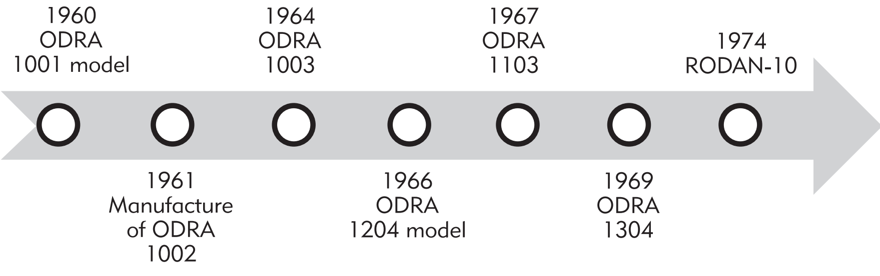

Fig. 20. Evolution of the ODRA computer series, part 2

Source: Authors' own study based on ELWRO [1989]

was the implementation of drum memory as the internal memory. All ODRA machines including the 1013 model (also UMC-1) had drum memory and all of them except the 1001 model were non-sequential. Magnetic-core memory was introduced for the first time in an ODRA 1013 model compatible with the previous 1003. The ODRA 1204 was the first machine to have the entire RAM memory based on ferrite cores [Komorowski 2002].

In 1962, the first unit UMC-1 digital machine unit which operated in negabinary arithmetics was launched [Bilski 1989]. Its prototype was developed in 1960 at the Company's Club of Technology and Rationalisation at the Warsaw University of Technology. In 1965, the UMC 10 machine i.e. a transistor version of the UMC-1 machine was launched [Madey and Sysło 2000]. In the years 1963––1964, 25 UMC-1 digital machines were manufactured. Thanks to the good software developed with the participation of mathematicians from the Warsaw University of Technology and the Wrocław University of Technology, the UMC-1 computers were used in computations related to cartography and land surveying.

The UMC-1 was a large-sized vacuum tube machine, energy-intensive and becoming very heated, therefore it required intense cooling. It was equipped with drum memory with a capacity of 4096 36-bit words, and reached a speed of 100 additions per second. On the input and, at the same time, on the output the machine had a teleprinter with a tape punch [Zuber 2015].

The UMC-1 machine was a fully vacuum tube based device, and its technical capabilities were not much different from those of the ODRA 1001 and ODRA 1002 machines. The ODRA 1003 model (the second generation – transistor technique) was made in 1962, and a prototype a year later (Fig. 21, Fig. 22). In 1964, serial production was launched. In the years 1964–1965, 42 ODRA 1003 units were manufactured [Maćkowiak et al. 2018]. The ODRA 1003 computer with serial and dynamic information processing, equipped with fixed- and floating-point subprograms, had only a teleprinter, paper tape reader and punch and an analogue-digital converter for the input-output devices [Urbanek 2019]. At that time, at the Department of Numerical Methods at the University of Warsaw, the Autokod Most 1 for the Odra 1003 machine was made as well as two implementations of the Algol 60 language and their translators; at a later time, the MASON operating system and a library of approximately 200 basic numerical algorithms for the ODRA 1204 machine were completed as well [Madey and Sysło 2000].

In June 1965, a prototype of an improved version of the ODRA 1003 computer machine with a name of ODRA 1013 was built. It was a second-generation computer built based on germanium diodes and transistors, equipped with a drum and magnetic-core memory with a capacity of 256 words, and software adopted from the ODRA 1003 machine [Maćkowiak et al. 2018]. This made the ODRA 1013 twice as fast as its predecessor (up to 2.8 thousand operations per second). The ODRA 1013 was introduced into serial production in 1966 [Madey i Sysło 2000]. Another version of the ODRA computer was ODRA 1103 equipped with extended magnetic-core memory and system drum memory [Urbanek 2019].

Urbanek [2019] pointed out that ODRA 1001, 1002, 1003 and 1013 were simple digital machines (as compared to modern computers) using the serial computing method (single-bit adders). Each of them required individual adjustment to

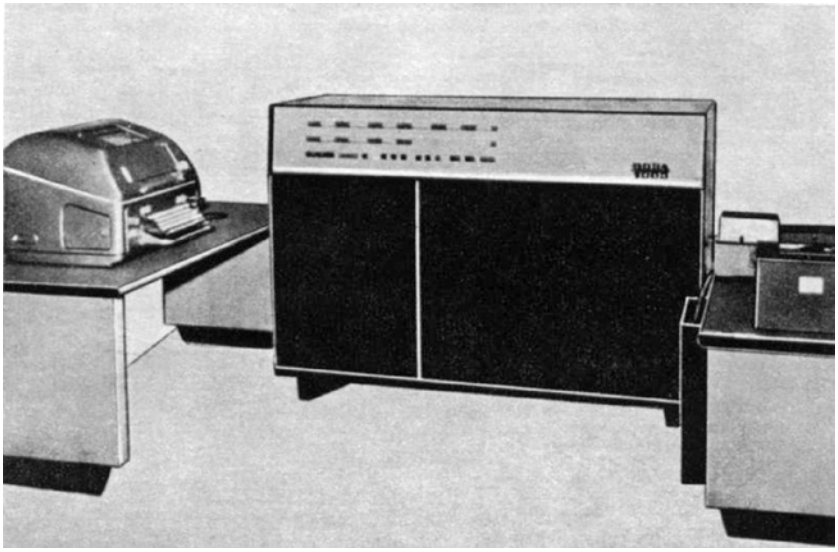

Fig. 21. ODRA 1003 digital machine
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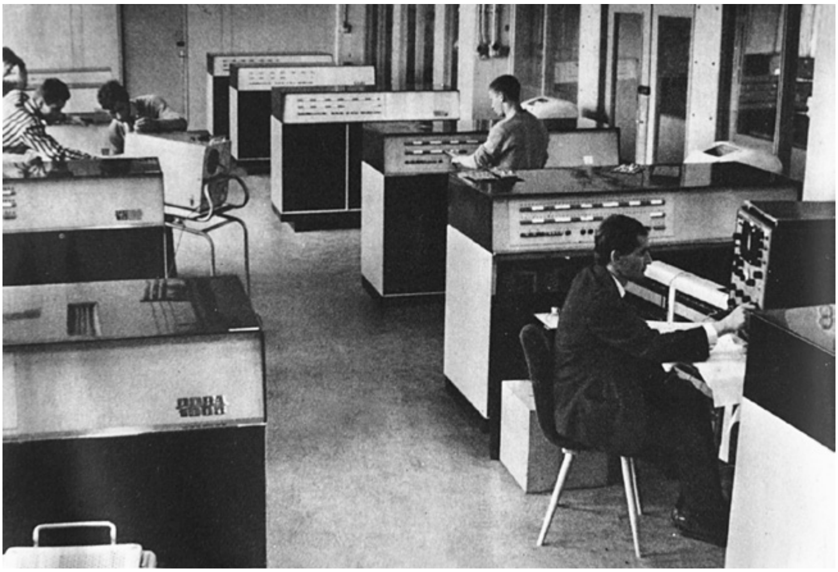

Fig. 22. Initial operation of Odra 1003 computers
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the current speed of information flowing from the magnetic drum that was the heart of the system. They were, however, reliable in operation and despite their low performance they allowed simple yet arduous and time-consuming algorithmic computations to be carried out.

Fundamental progress in the development of Wrocław computers was achieved at the time of designing the ODRA 1204 computer machine built using the transistor technique. The microprogrammed implementation of the central processor's commands, unique at that time, was used for the first time in Poland in the ODRA 1204 digital machine. The second generation of digital machines had "parallel" logical structure i.e. it enabled simultaneous processing of 24-bit words (parallel adder), controlled through microoperations located in the read-only memory (ROM) with a capacity of 1K words [Urbanek 2019]. In the years 1968–1972, 179 units of the ODRA 1204 were produced, of which 114 were exported. ODRA 1204 was among the best digital machines produced at that time in Eastern and Central European countries [Maćkowiak et al. 2018].

A model of the ODRA 1304 processor was developed in mid-1968 as a result of only one year's designers' work. Not without significance was the fact that its design was based on many previously proven solutions used in the serial production of the Odra 1204 computer machine. At the same time, however, in terms of technical aspects as well as internal and external equipment, the ODRA 1304 computer machine differed substantially from its prototype i.e. British ICL 1904.

A standard operating system for the ODRA 1304 machines (ICL 1904) was the Executive E6BM management program (Batch processing Mode) designed for efficient batch jobs. The system usually resided on magnetic tapes, which earned it the designation of "tape executor" [Urbanek 2019]. Digital machine ODRA 1304 was designed to accept the ICL software. A relevant agreement in this matter was concluded between the ICL and Elwro. However, the basis for the Odra 1304 design was only the list of commands provided by the ICL and a detailed description of all instructions. The performance of a software agreement was, at that time, a unique achievement on a global scale. Polish computer science fully opened up to the West [Bilski et al. 2017, p. 22]. Thanks to the agreement concluded with the ICL, all computer products of the Odra 1300 series were well equipped with software in terms of the system, tools and applications [Urbanek 2019].

The ODRA 1304 system (Fig. 23) comprised new peripheral devices including the CT-304 paper tape reader, the DT-304 paper tape punch and the CK-304 punched card reader; however, the most important device for entering information was the DW-304 line printer. In January 1970, the first public demonstration of program compatibility between ODRA 1304 and the ICL 1904 computer was held at the ZETO in Wrocław [Maćkowiak et al. 2018]. The demonstration was a successful event.

Fig. 23. ODRA 1304
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All second-generation computers except the ODRA 1304 paved the way for the development of computer science in areas requiring scientific and technical calculations, in research and design work, at universities and institutes, in land surveying and meteorology, and at work in the country and abroad. The entities that have used ODRA computers are listed in a publication by B. Maćkowiak et al. [2018].

The Odra 1304 computer sets installed in Poland were the first stage of the establishment of national data processing systems at the ZETO of company's own computational centres, and were used in many economic sectors including mining, railway and energy as well as in banking and statistical institutions [Urbanek 2019].

5.2.2. ODRA 1305 system

A continuation of the 1300 series included digital machines of the third generation, namely ODRA 1305 and ODRA 1325 – both designed using the integrated circuit technique [Maćkowiak et al. 2018]. Two prototypical units of the ODRA 1305 system were made at the ELWRO Experimental Station, and launched in 1971 [Urbanek 2019]. In 1972, 8 units of the trial batch were produced, and in 1973 serial production was launched [Maćkowiak et al. 2018].

The ODRA 1305 unit was characterised *inter alia* by the possibility of addressing the operating score to a maximum capacity of 256K (262,144 24-bit words) installed in blocks of 32K or 64K, simultaneous operation of up to 16 utility programs under the control of the E6RM operating system, installation of a programmed clock to work out the operation of utility programs, installation of a real time counter necessary in the object-oriented control, microprogrammed implementation of all extra-code commands, and equipping the extended versions with the efficient GEORGE2 (tape) or GEORGE3 (disk) system [Urbanek 2019]. For the construction of the processor, the constructors used low- and medium integration scale integrated circuits, which allowed them to obtain better speeds in the Odra 1305 than those in its English equivalent i.e. the ICL 1905/1906 machine [Bilski et al. 2017].

The biggest advantage of the Odra 1300 series machines was extensive software operating under the control of the GEORGE system, including Algol, FORTRAN and COBOL programming systems, JEAN conversational language, CSL and SIMON simulation languages, a wealthy library containing more than 1000 standard procedures and 15 packets of utility programs in the field of planning and management [Zuber 2015].

In the years 1973–1983, the number of ODRA 1305 systems delivered by the ELWRO for processing amounted to 362 computer sets, about half of which were exported to the neighbouring countries of the so-called socialist state bloc (members of the Council for Mutual Economic Assistance, CMEA). At that time, it was a system with a high performance comparable only to certain products of the IBM 370 series which were then virtually unavailable [Urbanek 2019]. According to Maćkowiak et al. [2018], 337 ODRA 1305 sets (systems) were installed for both domestic and foreign customers from 1972 to the end of 1980.

5.2.3. ODRA 1325 means "modern"

ODRA 1325 was equipped with a parallel asynchronous processor using binary, complementary arithmetics on fixed-point (24b) and floating-point (48b) numbers. Mechanical design of the ODRA 1325 computer machine comprised a packet with dimensions of 140 × 150 × 1.5 mm, interacting with an 84-contact indirect connector and 1, 2 and 4-layer packets with metallised holes. On the packet of 30 integrated circuits, 42 packets formed 1 panel, and 4 panels formed 1 frame. The central unit was comprised of 4 modules with dimensions of 800 × 750 × 250 mm, and weighed 250 kg.

In the 1970's, ODRA 1325 was a modern device characterised by: modularity, concurrent processing, multiprocessing (2 processors), multi-user software, real-time operation, flexible configuration, fast and high-capacity internal memory, expandability, priority interrupts, memory field protection, modern components and technology (at least on a socialist country scale), hybrid integrated circuits and extensive software (including the EXECUTIVE GEORGE and MOP operating systems). In terms of the architecture, the closest equivalent of the ODRA 1325 computer machine (but with lower usability) was the ICL 1903 computer [Letki 1972]. ODRA 1300 series computers were reliable. Their high availability was proved by the failure-free operation rate of no less than 0.999 (less than an hour of stoppage per month; an average time of rectifying a failure was approx. 30 minutes [Urbanek 2017]. Moreover, it was possible to equip them with many peripheral devices (Table 1).

Table 1. Peripheral devices for the ODRA 1305 and 1325 computers, produced by Elwro

Device type	Model
tape reader/punch	CDT-325-2
card reader	CK-325-1
line printer	DW-325-1
tape memory controller	MTS
disk memory controller	SDS
teleprocessing multiplexer	MPX-325
inter-machine adapter	ADM-305
data transfer device	UPD-305

Source: Authors' own study based on Maćkowiak et al. [2018]

ODRA 1325 was dedicated to applications operating in real time e.g. those controlling industrial technological processes. In the years 1973–1979, a total of 151 ODRA 1325 computers were manufactured, of which 24 were exported.

5.2.4. Who used ODRA computers?

The GEORGE3 (EWG3) system that the ODRA 1305 computers were equipped with attracted the interest of large enterprises, especially those which, apart from batch jobs, were looking for a system that allowed the production process to be managed on an ongoing basis in a concurrent processing operation mode [Urbanek 2019].

The basic field of application of the ODRA 1325 computer was the automation of a technical process control including the control of automated industrial processes, data processing and the performance of scientific and technical computations [Letki 1972]. The Odra 1305 sets installed in Poland were the core of data processing in ZETO computational centres and company's own ETO centres, in the central and regional statistical offices, in banking institutions as well as in the mining, energy and railway sectors, e.g. in the non-ferrous metal processing plant Hutmen [Urbanek 2019] or at the rolling mill in Nowa Huta and at the Nuclear Physics Institute in Novosibirsk. For a few decades, the ODRA 1300 series double-machine sets were not only used to manage and optimise the rolling stock (e.g. they helped operate the switch yard of the Skarżysko Kamienna and Kielce Herbskie Eastern District or the Wrocław Brochów railway station) but primarily to automate on-line processes (real-time control) at switch yards in major signal towers of the main Polish railway junctions [Urbanek 2017].

ODRA 1325 computers were also used for military purposes [Maćkowiak et al. 2018] and in higher education, e.g. at the Wrocław University of Science and Technology or the University of Wrocław [Zuber 2015, Bilski et al. 2017].

On 30 April 2010, at the Computer Science Centre in Lublin, the Polish State Railways PKP Company Branch, the operation of the last teleprocessing computer system running based on the Odra 1305 processors was terminated. The set was officially disconnected from the supply network on 1 May 2010 i.e. after 34 years of continuous three-shift operation at one of Poland's major switch yards for the PKP freight traffic [Urbanek 2017].

5.3. ELWRO 801 AT personal microcomputer

In 1986, the ELWRO 800 Junior microcomputer was built, and 1987 saw the emergence of the ELWRO 801 AT (Advanced Technology). The ELWRO 801 AT (abbreviated to E 801 AT) computers resemble the currently operating desktop PC units (Fig. 24).

The AT standard was made available in 1984 by IBM; it was distinguished by, *inter alia*, a fixed switch (an element of the feeder) which turned the device on or off; first, the operating system needed to be shut down, and the computer power to be turned off. The AT computer also had a single DIN connector for connecting a keyboard.

The ELWRO 801 AT was equipped with an Intel 80286 (6 or 8 MHz) processor, 512 kB RAM memory (expandable up to 2 MB), a 20 MB hard disk drive, a $5^1/_4$ inch floppy disk drive, EGA graphics, a keyboard, a Unitra Polkolor MM-12P monochromatic display unit (or a Unitra Polkolor MM-14SP colour display unit) and the MS-DOS 3.3. operating system [ELWRO 1989].

ELWRO 801 AT was an IBM PC/AT class hardware and software set. A standard E 801 AT set was comprised of the central unit with $5^1/_4$ inch floppy disks with a capacity of 360 kB 1 piece and 1.2 MB 1 piece) and a hard disk drive

($5^1/_4$ inch with a capacity of 20 MB), a monochromatic video display unit (POLKOLOR 12' of the MM 12 type, HERCULES-type graphics driver, a maximum resolution of 720 x 348 points), a keyboard (AT-type, 84 keys), software (MS-DOS 3.3) and the operational documentation [Bartoszewicz et al. 1987].

The casing of the ELWRO 801 AT microcomputer central unit comprised a metal spatial structure, a plastic front panel, the microcomputer status indication system, and a lock with a key. The ELWRO 801 AT central unit was comprised of the packet of a CPU Intel 80286 processor, 512 kB RAM memory, the BIOS program, eight slots for additional packets (cards), a socket for the INTEL 80287 co-processor and a 200 W power pack [Bartoszewicz et al. 1987].

The optional components of the ELWRO 801 AT included a POLKOLOR colour display unit along with an EGA-type controller card, a printer and a mouse-type manipulator (via the RS 232 C connector). Other devices included e.g. a high-resolution display unit, an X–Y plotter, a digitiser, a scanner or a text and graphic terminal [Bartoszewicz et al. 1987].

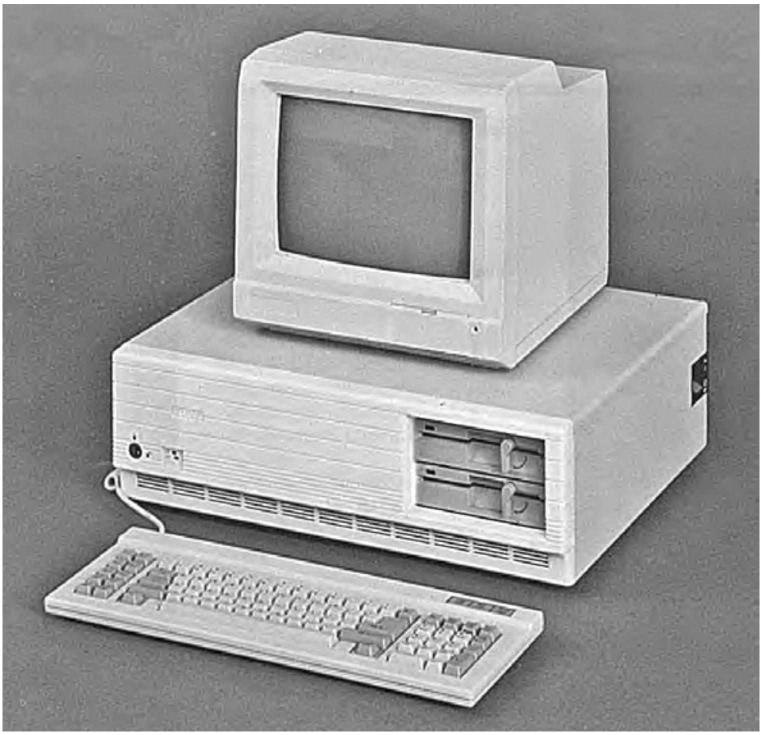

Fig. 24. ELWRO 801 AT
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In 1988, production of ELWRO 801 AT personal microcomputers was launched. ELWRO 801 AT computers were compatible with IBM PC/AT and equipped with software manufactured by Microsoft for which ELWRO became an authorised distributor [Maćkowiak et al. 2018]. An Intel 80286 microprocessor was used in the microcomputer. The motherboard and casing were designed in Poland (a 2-layer motherboard). Approximately 1100 Polish motherboards were manufactured. Later on, a cheaper and more stable Taiwanese version was installed in ELWRO 801 AT microcomputers [Kaźmierczak 2017].

The ELWRO 801 AT microcomputer, depending on the operating program and the software tool or utility software, was more or less commonly used. The microcomputers could be connected into local networks or multi-access systems, and operate autonomously or as computer system terminals e.g. the ES EVM (Unified System of Electronic Computers).

Although this is obvious now, in the 1980's the advantages of a microcomputer such as the possibility for editing texts and drawing up documents using a text editor were highlighted. According to Bartoszewicz et al. [1987], the considerable graphic and colour capabilities of the E 801 AT microcomputer placed it among the best tools for supporting design work *inter alia* using the AutoCAD. The computer was also used to manage a relational database (e.g. dBASE III PLUS or RBASE), which allowed it to be used in a wide variety of ways, for instance in industry or management, or for scientific purposes. Creating various utility programs was facilitated by the programming languages TURBO-PASCAL, the C language, GW BASIC and most of the Microsoft compilers which operated correctly on the E 801 AT.

The ELWRO 801 AT microcomputer was used in accounting and the support of office work, including banking (at that time it was used by units of Polish bank Powszechna Kasa Oszczędności PKO). It was used as a "multi-access set" i.e. (an extended) central unit equipped with e.g. three (terminals) display units with a keyboard and a printer. The resulting multi-station set was much cheaper to complete than several independent personal microcomputers. The ELWRO 801 AT could therefore be used in general purpose network sets, in editorial, design and other specialist applications.

5.3.1. ELWRO 800 Junior

The ELWRO 800 Junior microcomputer (Fig. 25) was developed as a microcomputer for school purposes. It was intended for educational establishments as well as for households as a personal microcomputer for work, study and play; in businesses, it was used as a microcomputer for data processing which offered a possibility for communication with other computers. The ELWRO Junior was equipped *inter alia* with a Z-80A microprocessor, paged operating system

(64 kB RAM, 24 kB EPROM), a colour graphics chip, a sound generator chip and a local computer network unit. It could be expanded to include an input-output circuit e.g. a printer or a control column (joystick). The ELWRO 800 microcomputer was equipped with the CP/J disk operating system that was fully compatible with the CP/MV2.2 system. The CP/J system enabled the connection of several ELWRO Junior computers into a simple local network [ELWRO 1989].

It is worth mentioning that the ELWRO Junior was equipped with a cassette store control unit (a standard cassette recorder). All programs written for the Spectrum computer (1982, a Zilog Z80A/Z80B processor @ 3.5 MHz) could be loaded from a cassette player onto the ELWRO 800 Junior, which allowed the "800" users to use the extensive Spectrum software library without problems [ELWRO 1989].

The Elwro 804 Junior model was introduced to the market in 1990. This version was intended for home use, and had the following specifications: a Z80A processor, 64 kB RAM memory, 24 kB ROM memory, a 256 x 192 graphics capability, a 16 colour capability, 1-bit sound generated by the software, a 3.5' DS/DD floppy disk drive (720 kB), a CP/M or, alternatively, ROM-BASIC system (compatible with Spectrum). Until 1991, approximately 150 units were manufactured [Maćkowiak et al. 2018].

Fig. 25. Elwro 800-2 Junior computer workstation. Serial number 88004524
Licence: CC BY 3.0 (author: Marcin Robert Kaźmierczak)

Source: pl.wikipedia.org

The serial production of the ELWRO Junior was launched in 1987. A few thousand schools in Poland were equipped with the school microcomputer, a large number of teachers were trained, and thanks to computer classes, more than a million Polish pupils were introduced to computer science [Maćkowiak et al. 2018].

5.4. Introduction to a history of Polish computer games

The gaming market in Poland did not grow until the 1980s. It was due to Poland being part of the Eastern Bloc, which posed certain limitations. Because of them, access to western computers, consoles, and software was restricted. The introduction of martial law in Poland on 13 December 1981 resulted in the militarisation of ELWRO, a Polish manufacturer of computers, and termination of import contracts for the supply of electronics for ELWRO following restrictions against Poland [Maćkowiak et al. 2018]. The fundamental problem that hindered mass production of video games in Poland was the permanent shortage of electronic components, the AY-3-8500 integrated circuit in particular (Fig. 26) [Kluska and Rozwadowski 2014].

The inventory of electronic components was scarce in Poland at the time, and they were hard to come by. The time necessary to make up the gap in access to modern components was estimated at up to ten years. To make matters worse, export and import were controlled by the Coordinating Committee for Multilateral Export Control (COCOM), which prohibited exporting modern technical equipment and advanced technologies from western countries to the Eastern Bloc [Maćkowiak et al. 2018]. The goal of the committee was to prevent Soviet Bloc states, and thus the Soviet Union, from gaining access to state-of-the-art goods and dual-use technologies. These could be used for both civilian and military purposes.

The internal policy of Poland was another obstacle in the growth of the video game industry. The permission to produce TVG-10, a Polish gaming console, was a rare case of the communist government allowing the creation and distribution to the general public of devices intended solely for entertainment [Kluska and Rozwadowski 2014].

Apart from that, microcomputers were relatively expensive due to duty and taxes imposed by the communist government. That meant that the price of ZX-81 (the predecessor of ZX Spectrum) bought legally was equal to a year's worth of salaries [Kluska and Rozwadowski 2014].

Nevertheless, difficulties for the growth of the Polish computer industry caused by Soviet interventionism started much earlier. In the 1960s, the top political and state authorities decided to commence cooperation between member states of the Council for Mutual Economic Assistance, a coordinating body for so-called "eco-

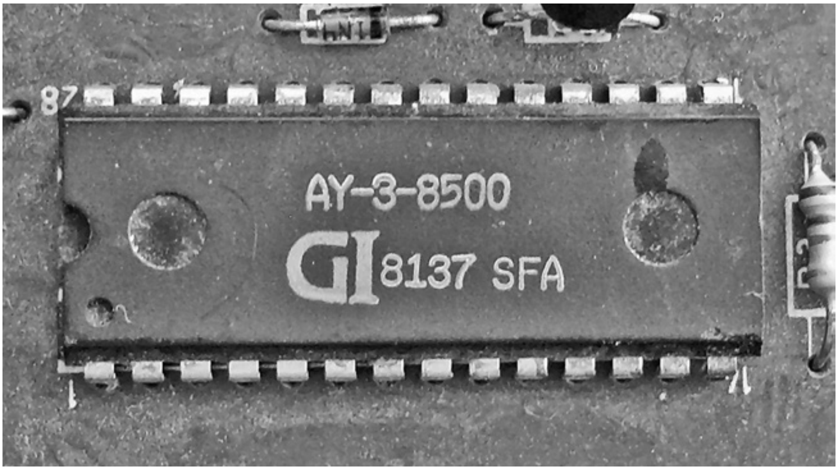


Fig. 26. AY-3-8500 integrated circuit

Source: pl.wikipedia.org

nomic cooperation" in the Eastern Bloc, and create the Unified System of Electronic Computers ES EVM, which did not include the ODRA family, which was much more advanced than Soviet products. Poland was tasked with developing the R-30 mainframe [Maćkowiak et al. 2018]. All these factors affected the development of the Polish software industry and future access to computers.

Video games from early times are becoming increasingly popular. New products have more and more solutions from the 8-bit or 16-bit era. Zealous gamers can be heard saying that "games used to be better" despite impressive video effects available today. Independent developers try to draw on their childhood gaming experience and spread the passion in younger generations. "Retro zones" are gaining in popularity with their exhibitions of old games, computers, and consoles from the 1970s or 1980s [Szewerniak 2018].

The oldest relics of electronic entertainment come not only from the US, where the software flourished the quickest, but also from Poland. Witold Podgórski created the puzzle game "Marienbad" at the beginning of the 1960s. It was played at the ODRA 1003 mainframe [Kluska and Rozwadowski 2014]. Because of the strategic importance of digital computers, high production costs, and their considerable size, Marienbad was developed in a governmental institution.

Two players took turns to remove matchsticks or cards arranged in rows on a table – the one left with the last object lost. The only way for ODRA to communicate with the user about the state of the game and the current card arrangement was through a teletypewriter (a telegraph printing device). Later, variants of the game became the second most popular type of computer game for Polish mainframes after noughts and crosses. “Szachy” (chess) and “Lądowanie na Księżycu” (moon landing) for ODRA 1003 followed soon. Results were still printed through a teleprinter, not on a screen. They were, therefore, strictly speaking, video games.

A set of simulation decision-making games became available in the 1970s. Players managed large companies through computer terminals using mathematical models. After each turn, the machine printed out the results from the entrepreneurs. At the end of the game, it gave the final score [Kluska and Rozwadowski 2014].

Mera-Elzab in Zabrze, southern Poland, designed the GEM-1 console in 1978. In Poland, gaming consoles were referred to as TV games or TV boxes at the time. Less than twenty devices were produced before the production profile was changed. Only basic technical documentation survived. It was obtained by Krzysztof Chwałowski from the Computer History Museum in Katowice from an employee of Mera-Elzab who had the last existing prototype of GEM-1 but disposed of it in 2012. This tangible relic of the history of Polish video games was irrevocably lost.

TVG-10, a TV video game with ten gaming modes, called “the Polish Pong”, has been the most popular Polish console. Unofficially, a trial lot of 200 devices was produced in 1978. A year later, TVG-10 (Fig. 27) was available in stores of the Zakłady Usług Radiotechnicznych i Telewizyjnych (state radio and television

Fig. 27. Ameprod TVG-10 and Neptun (Unimor) screen
Licence: CC BY-SA 4.0 (author: Jakub Hałun)
Source: pl.m.wikipedia.org

equipment manufacturer). The entertainment was in monochrome. Sounds resembled monotonous beeps.

The console had four games: “tenis” (classic Pong), “hokej” (hockey where each player had two bats, a forward and a goalkeeper, controlled simultaneously), “squash” (players took turns hitting a ball against the same surface) and “pelota” (a single-player squash). Players could also buy a light gun for shooting competitions. The Polish Pong was, most likely, manufactured until 1984 [Kluska and Rozwadowski 2014]. In the mid-1980s, Poland gained access to such microcomputers as ZX Spectrum, Atari XL/XE, or Commodore 64 with a virtually endless supply of games with outstanding graphics.

5.4.1. MERITUM-1: digital distraction in the Polish People's Republic

Computerisation gained momentum in the 1980s. Microcomputer IT became one of the fastest and most dynamically growing technical fields. The number of personal computers sold globally reached millions at that time [Korga et al. 1983].

The microcomputer industry was somewhat neglected in Poland at the beginning of the 1980s. The lack of a small, mobile, and affordable Polish computer was a significant problem [Korga et al. 1983]. In 1984, a new Commodore 64 with an original tape drive was about PLN 185 thousand. Amstrad Schneider CPC 464* (Fig. 28) with monochrome monitor was almost PLN 400 thousand. The price of the cheapest used ZX-81 was equal to six average salaries in 1984 [Kluska and Rozwadowski 2014, p. 28]. It cost PLN 4 million to establish a local network of ten MERITUM-1 handled by a MERITUM-2 in 1985 [Kaźmierczak 2019]. According to Korga et al. [1983], Poles would have been able to afford a computer set had it cost about PLN 200–300 thousand. “We believe that considering the current state of microcomputer technology in Poland and the current price of a computer, even wealthy families have no way of obtaining a microcomputer”. With the average salary of the time of PLN 20 thousand, millions of Poles could not afford a computer.

Poles could acquire or buy one unofficially or make it themselves (for example, with the guidance in the Audio-Video magazine). The Central Customs Office published statistics showing that individuals imported eight thousand microcomputers in 1985. The actual numbers will remain unknown [Kluska and Rozwadowski 2014].

MERITUM was exhibited for the first time during the Poland Fair in Poznań in September 1983. It was a Polish computer modelled after the TRS-80 Model II microcomputer manufactured from 1978 to 1983 by an American company, Tandy Radio Shack [Korga 1984]. The design of TRS-80 was relatively simple, which made it cheap to produce. Its capabilities, however, exceeded those of a typical household microcomputer.

Fig. 28. Amstrad CPC 6128
Licence: GNU Free Documentation License (author: NaSH)
Source: pl.wikipedia.org

The MERITUM personal computer was built entirely from Polish resources except for the U-880D microprocessor available through commodity exchange within the Eastern Bloc Council for Mutual Economic Assistance. MERITUM-1 (Fig. 29) consisted of microprocessor U-880D (a counterpart of Z-80), 17 KB of RAM, 14 KB of ROM, and 1 KB of video memory.

The mass production of MERITUM-1 commenced in the summer of 1984 in the Microcomputer System Assembly Department of Mera-Elzab in Zabrze, southern Poland. MERITUM-2 was first produced in the summer of 1985. It had 64 KB of RAM and Polish diacritics on the keyboard. The computer could be operated in Polish. In 1986–1987, Mera-Elzab started the production of MERITUM-3. About 100 prototypes were manufactured. It was the third and the last model in the family [Kaźmierczak 2019].

It was possible to type in (from a booklet delivered with the computer) and run a board game “mankala” (mancala), and an arcade game “duck hunt” into the “Polish computer”, MERITUM-1. Meritum supported TRS-80 games such as “ELIZA: zabawa w psychoterapię” (a psychotherapy game), “BOUNCE: zwalczanie obiektów kosmicznych” (space shooter), “OTHELLO: gra starożytna”, or “CAR:

Fig. 29. Meritum-1 – basic set
Licence: CC BY 3.0 (author: Elkon Elektronika)
Source: pl.m.wikipedia.org

jazda samochodem". The few gamers from that time may still be emotionally attached to "Robak Franciszek", a version of the famous "snake" [Kluska and Rozwadowski 2014].

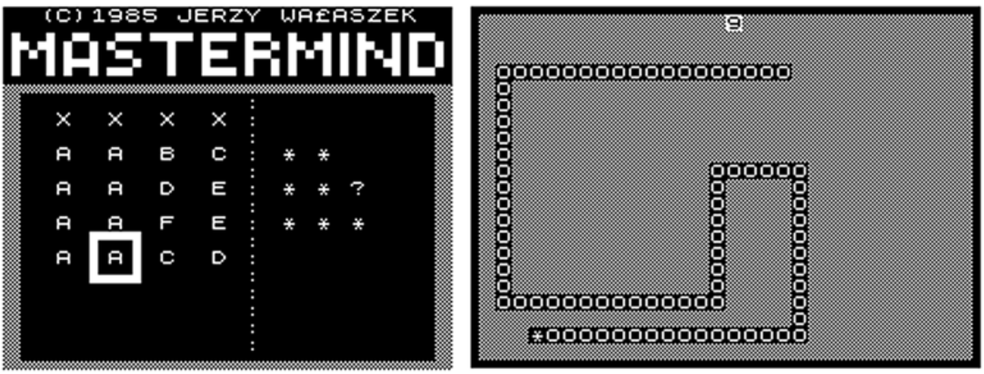
MERITUM was not a successful design. Piotr Biedrzycki wrote in the IKS magazine in 1988: "Meritum has scarce software. Its poor graphics, lack of colours, and limited sound capabilities do not encourage to write programs, games in particular" [Kluska and Rozwadowski 2014, p. 54]. Here are some selected imperfections of MERITUM: its software was a one-to-one copy of TRS-80, which meant that the Polish microcomputer, intended mainly for Polish schools reported in English. It was not capable of supporting Polish diacritics, which were absent from the keyboard [Kaźmierczak 2019]. Users reported significant increases of the microcomputer's and its power supply temperatures, especially after extended operation. It could be the reason for the computer's failures and disturbed behaviour. The technical documentation about the microcomputer (31 A5 pages) was poorly compiled. It failed to provide thorough knowledge about the device [Chrześcijański and Żebrowski 1985].

In 1985, the Pewex chain of state-owned "luxury" stores offered Atari – Personal Computer. The device came with a warranty and authorised technical support. A 1988 survey among readers of Bajtek left no doubt. Almost two-thirds of the respondents owned a "small" Atari, while the others had various types of Spectrum or Commodore machines [Kluska and Rozwadowski 2014].

The game “Żabie zawody” simulated a frog jumping contest. It taught computer science to users who typed in listings in BASIC or Logo into the computer’s memory. The type-in listings were published in magazines such as Bajtek. The program first drew a table on the screen (two vertical lines and one horizontal line) and then put the “&” characters, the “frogs”, on the left edge – the frog that jumped the furthest won unless it fell off, which meant disqualification.

Another example was the listing for “Nessie” by Janusz B. Wiśniewski, also published in Bajtek. The user could enter the source code into the memory of their Atari line by line. The game involved shooting objects on the screen. Bajtek published many listings with which users could create games on their machines. A work with too many lines to be published in Bajtek was “Miauczur” by Przemysław Siwiński. It was a platform game created for Amstrad where the user moved a cat in a world of traps, mice, and dogs. The game was never commercialised and has been lost without a trace on a three-inch disk [Kluska and Rozwadowski 2014].

One of the first Polish authors of entertainment software was Jerzy Wałaszek, who created, among other software, logic games including jigsaw puzzles, the computer adaptation of “Mastermind” (Fig. 30a) or the arcade game “snake” (Fig. 30b) between 1984 and 1985. All of them survived because their source code was written down in a school notebook. They are probably the only completely original Polish programs for ZX-81 that lived to see this day [Kluska and Rozwadowski 2014].



(a) (b)

Fig. 30. Mastermind game (a) for computer ZX-81 by Jerzy Wałaszek (screenshot); Snake game (b) for computer ZX-81 by Jerzy Wałaszek (screenshot)

Source: archiwum speccy.pl

“Barman” was one of the first Polish microcomputer games. The player was a bartender tasked with serving beverages to customers – a failure to do that meant game over [Kluska and Rozwadowski 2014]. “Barman” was a clone of a popular game, “Tapper” circulated among players as a listing in the mid-1980s. A “copy” of “Barman” can be found in the IKS magazine, which published the code for Meritum in 1988. The probable author of the code was Piotr Biedrzycki. He published a shooter, “Nietoperze”, in IKS as well. The game involved bat shooting. According to Kluska and Rozwadowski [2014], these are most probably original works, really Polish games for Meritum, which survived until today as source code.

5.5. The computer mouse as an artifact

As late as the 1990’s, tutorials and specially designed games were added to the Apple and Microsoft computer software to make it easier to learn how to use a computer mouse. In 1992, the first chapter of the “Macintosh User’s Guide” was titled “Using the Mouse” [Atkinson 2007].

The story of computer mouse origins is often simplified and boiled down to a relatively uncomplicated scenario: Douglas Engelbart and his co-workers from the Stanford Research Institute invented the mouse in the 1960’s, and then innovators from the Xerox Palo Alto Research Center improved the invention in the 1970’s. When Steve Jobs saw it in 1979, he decided that his company Apple Computer would introduce it to the market.

The first computer mouse was invented by Douglas Engelbart at the beginning of the 1960’s. The invention was presented publicly during the famous multimedia demonstration Fall Joint Computer Conference in 1968 (AFIPS ‘68) in Menlo Park and San Francisco (a presentation entitled “A research center for augmenting human intellect”). The first computer mouse resembled nothing like those used nowadays; it was a large-sized wooden object with three push-buttons that was a component of the pioneering online system intended for learning and network-based cooperation (Fig. 31). It was designed to enhance advanced computer users’ capabilities and not to provide support for beginners [Pang 2002].

In 1957, Douglas C. Engelbart submitted an application for the position of scientist at the Stanford Research Institute. There, for many years he conducted research into the interactive use of the computer yet was not very successful, largely because what he was working on at the time could have seemed like “proposing that everyone would soon have his own private helicopter”. For years, he carried out experiments with “light pens, tracking balls and other kinds of gadgets”. Based on Engelbart’s notes, his colleague Bill English built in 1960 a prototype of the device that was a precursor of the computer mouse. It took the form of a relatively large-sized wooden box with a single push-button and wheels attached to the internal potentiometers [Atkinson 2007].

Experiments quickly revealed that the device had great potential. After a few months of testing, users selected the "mouse" from all innovative solutions as the device which best met their expectations [Logitech 1993]. It was then that the device was given the name "mouse". As Engelbart recalls: "I didn't give it the name while carrying out all those experiments. I never called it a mouse. Successful experiments gave us confidence that the device would be marketed worldwide, and that manufacturers would give it a suitable name. We referred to it as an 'X–Y positioning device' or used a similar term" [Engelbart 2006]. Apparently, however, the device had been given its pseudonym much earlier when someone (and nobody seems to remember who it was), while seeing the prototype in action, blurted out: "this thing looks like a mouse with a single ear!" (D. Engelbart's statement as cited by Moggridge 2006).

At the beginning of the 1970's, during research on computers that was carried out at Xerox's Palo Alto Research Center (PARC), the mouse was connected to the graphical user interface (GUI). The research was carried out using high-class computer systems, namely "Alto" (1972) and "Star" (1981). Bill English who left the Stanford Research Institute to join Xerox in 1971 developed, in cooperation with Jack Hawley, a new version of the mouse in which they used a single ball of steel for the very first time. The ball activated two internal encoders to measure the motion within each plane. The mouse became smaller and flatter, and its small round push-buttons were replaced with large rectangular ones [Pang 2002]. It was with a Xerox Alto computer and software called "Gypsy" in 1975, that the mouse was first used "as it is today", to execute point-and-click operations [Hiltzik 2000, p. 210].

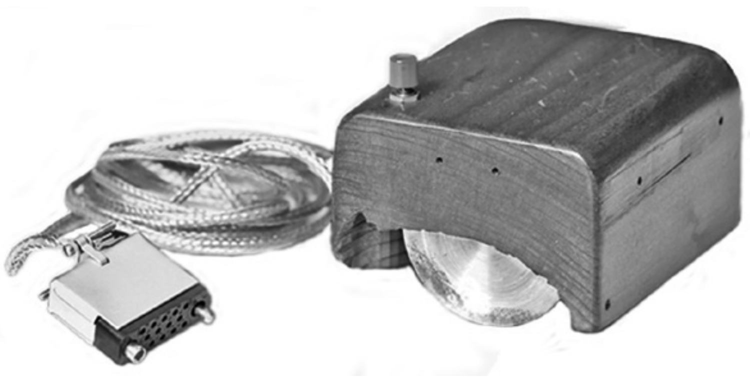


Fig. 31. A prototype of the computer mouse
Licence: SRI International (CC BY-SA 3.0)
Source: commons.wikimedia.org

The Xerox PARC computer mouse was introduced to the market in the late 1970's, and could be purchased for 400 USD. Users also had to spend 300 USD more for an interface enabling its connection to a computer. Due to the high price of the set, however, it was not purchased by many people [Pang 2002].

Prior to the introduction of Apple Lisa (a personal computer designed by Apple Computer), computer mouse devices were expensive and unreliable. Due to the complexity of design, it cost from USD 350 to 400 to manufacture a mouse. Xerox mouse devices, although innovative at the time, were not suitable for mass production. The interior steel ball was held in a precision-machined metal assembly that had to be precisely aligned with internal rollers and springs in order to work properly. When in use, the mouse collected dirt and debris off the work surface, which affected its performance, and it had to be disassembled in order to be cleaned [Atkinson 2007].

Dean Hovey, Jim Sachs, Jim Yurczenco and Rickson Sun were part of the Hovey-Kelly design team which commenced work on the mouse that was to be supplied with the Apple Lisa computer. The steel ball was replaced with a small, rubber-covered lead ball, and all mouse components were enclosed in an ergonomic, lightweight casing. It was suggested that these changes were probably the most significant in the history of the mouse: "Apple moved the mouse from the laboratory to the living room" [Pang 2002].

Rickson Sun recollected that Steve Jobs approached the design team members with a Xerox mouse and said: "Hey, what can you do to help me with this? I cannot sell these for 350 USD, but for 15 USD I could sell a ton of these" [Sun 2006]. Steve Jobs wanted a 90% cost reduction and a radical improvement in the reliability of the mouse.

The mouse was developed at the Stanford Research Laboratory in 1965 as part of the NLS project [English et al. 1967]. It was supposed to be a cheap substitute for lightweight pens that had been used since ca. 1954. Many current applications of the mouse were demonstrated by Doug Engelbart as part of the NLS in a 1968 film. The mouse became known as a practical input device thanks to Xerox PARC in the 1970's. It appeared for the first time on the commercial market as part of the Xerox Star (1981), Three Rivers PERQ (1981) [Myers 1984], Apple Lisa (1982) and Apple Macintosh (1984) [Myers 1998].

5.6. The story about the computer keyboard

The first most successful and globally recognised model of a modern computer keyboard was IBM Model M keyboard manufactured since 1984. Keyboards in the present form were originated based on the input-output devices in computers such as ENIAC or UNIVAC, although the history of the keyboard itself and the typing technique dates back to the 17th century.

It is difficult to describe the development of a computer keyboard while ignoring the history of writing machines (devices), and the first patent in this field appeared as early as 1714 in England. The writing devices were a response to the need for drawing up documents in a neat and legible manner, and in a standardised format [Metadot 2019].

The keyboards in the present form were initiated based on the input devices in computers ENIAC (1946), BINAC (Binary Automatic Computer, John Presper Eckert, Jr. and John William Mauchly, 1947–1949 [Stern 1979] and UNIVAC (Fig. 32) (Universal Automatic Computer, designed and constructed by John Eckert and John Mauchly in 1951 [Eckert 1951]. These computers used the so-called Teletype Input Devices to enter data. The physical data carrier was punched cards, although in the BINAC computer, another input-output method with the electromagnetically controlled teletype was applied to enter data and print results [Metadot 2019]. BINAC was the first completed electronic digital computer of that type. It comprised the main computational section, the input-output devices and the mercury delay-line memory with a capacity of 512 words [Auerbach et al. 1952].

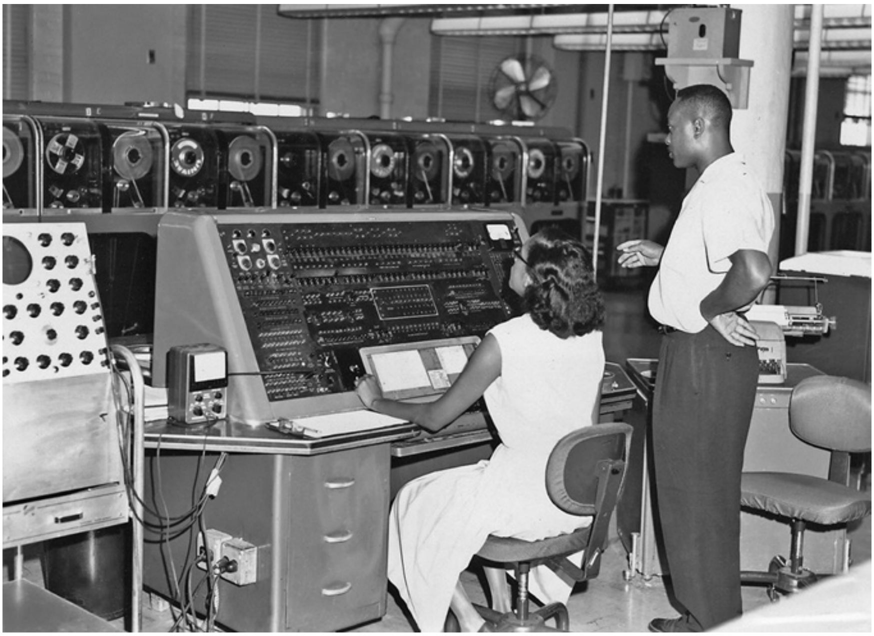


Fig. 32. U.S. Census Bureau employees tabulate data using one of the agency's UNIVAC computers, ca. 1960
Licence: public domain (author: U.S. Census Bureau employees)
Source: commons.wikimedia.org

In 1965, the companies Bell Labs, General Electric and MIT created MULTICS. Multics (Multiplexed Information and Computing Service) is a mainframe time-sharing operating system that was developed as a research project until the year 2000 [Multics 2019]; it was implemented on the GE 645 computer [Corbató and Vyssotsky 1965]. Text was displayed on the display terminal as it was being written, which made it more efficient to transfer commands and programs to the computer than when applying the previous methods for entering text. In the late 1970's, all computers used a VDT and electric keyboards. The first keyboards that were sold in the 1970's were heavy and fully mechanical. As a product, they were primarily aimed at programmers and engineers, therefore they were designed to be functional rather than appealing to the eye. However, it was then the simplest and most user-friendly method of interaction with a computer (no stack of punched cards) [Metadot 2019].

At that time, there were also "keyboards" built into computers. In mid-1970's, the Imsai and Altair created the first small computers for personal use, generally called S-100 computer systems, e.g. MITS Altair 8800 (Fig. 33) (computers based on the S-100 bus boards) [Langlois 1992]. These machines were the first home computers used before the IBM-PC, Apple and other computers were in existence. The common denominator for the S-100 systems was that all of them were designed based on a board with an edge card connector comprised of

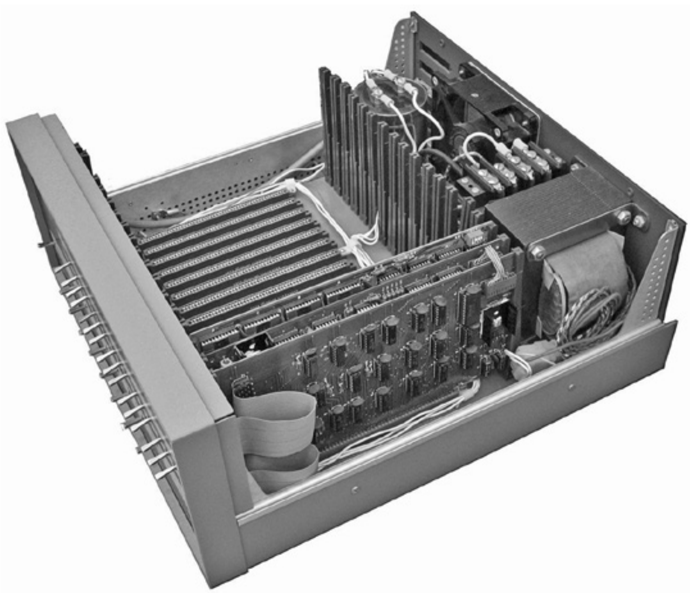


Fig. 33. MITS Altair 8800b
Licence: public domain (author: Michael Holley)
Source: pl.m.wikipedia.org

100 pins. Many various boards, including the Front Panel Board, CPU Boards, Memory Boards, I/O boards, video boards, Cassette and Floppy Disk Controller Boards or Hard Disk Controllers could be connected to the S-100 bus. Manufacturers offered a variety of unique boards yet, generally, all of them operated based on the S-100 bus. Probably as many as 1000 various types of the S-100 boards were sold from 1976 to the mid-1980's.

The S-100 bus was initially designed for 8-bit processors. Later on, it was converted into a bus for 16-bit processors, and approved as an IEEE-696 bus. Currently, computers based on the S-100 bus are coming back into favour with collectors who restore them and "keep them alive" [S100 2019].

The S-100 bus-based machines were constructed piece by piece and offered basic functionalities. There were no hard drives in these early computers (storage: paper tape, cassette or floppy drive), therefore no data could be recorded on them. A "keyboard" was located at the front computer panel in the form of a set of switches [Metadot 2019].

At the end of the 1970's, Apple, Radio Shack and Commodore began manufacturing keyboards for their computers and thus paved the way for the then innovative assumption that all computers should be equipped with a keyboard as a basic input device [Metadot 2019].

In 1981, the first IBM computer appeared on the market, and in 1986 it was equipped with the Model M keyboard. This keyboard was an unprecedented success because it was so easy to use that the users did not need to convert their typewriters or provide their own version of the keyboard as an input device. Model M was a mechanical keyboard of the highest quality. The only drawback of that device was that the "Shift" and "Enter" keys were allegedly too small for most users. For this reason, IBM produced and sold "Keytop Expanders" i.e. specific replacement keys. At that time, computer keyboards were offered in two colours, beige and grey, until the end of the 1980's when the manufacture of black keyboards was launched [Metadot 2019].

The IBM's Model M keyboard is a rare element of electronics or the computer technology, that is both a "historical" object and a useful tool in the modern computer environment (Fig. 34). IBM's Model M keyboards are unique as each of them is marked with an individual serial number. These keyboards were manufactured by the IBM and Lexmark in the 1980's and 1990's, until 1999. Under each key, a separate spring is located which, when pressed, converts the physical force into an electric signal. Currently, most keyboards use a cheaper technology based on rubber pads. Moreover, inside each keyboard there is a curved steel plate which ensures durability and an ergonomic typing angle. Individual keys can be easily removed to clean the keyboard or change its format for different languages. Finally, the inscription on each key is integrated with its upper plastic part (it is not spray lacquered or stuck on as in cheap keyboards) [Ermita 2015].

Fig. 34. IBM's Model M keyboard. German keyboard layout (QWERTZ, ISO-DE)
Licence: SRI International (CC BY-SA 4.0)
Source: commons.wikimedia.org

Nowadays keyboards are available in all shapes, sizes and colours. In the 1990's, the mechanical key switch was replaced with a membrane key switch that was quieter and lighter, and addressed the needs of the new generation of laptops. Membrane keyboards were also much cheaper to manufacture [Metadot 2019]. Nowadays, the most common key layout on a keyboard is the so-called QWERTY design (the name comes from the order of the first six keys on the top left letter row of the keyboard).

5.7. Digital Vellum

It is doubtful that people will be able to use currently created digital contents in 20 or 30 years, not to mention 100 years, even though they will still be able to interact with these materials. What is worrying is the fact that with the increasing volume of digital data, a large portion of them may be inaccessible to future generations due to the bit rot phenomenon [Hayes 1998, Odersky and Moors 2009]. Bit rot refers to the irrevocable degradation or loss of digital information when the infrastructure (the hardware and software) required to access, interpret, view, and use this information is no longer available or executable [Kosciejew 2015, p. 20].

A certain kind of panacea to the bit rot phenomenon is the concept of so-called Digital Vellum. The author of the Digital Vellum concept is Vinton Gray Cerf (Vint Cerf). Vellum is a high-quality parchment made from animal skins, synonymous with a durable, luxurious content carrier [Cerf 2011]. Digital Vellum is the consolidation of the digital ecosystem along with its existence-supporting infrastructure i.e. a kind of an X-ray image of the contents of disks, applications and the operating system including a description of the machine. Digital Vellum assumes that this “digital snapshot” should be preserved in order to reproduce the past in the future, all of this to preserve information about files, software and hardware for future generations [Mottl 2015].

The main components of Digital Vellum are standardised descriptions which are to ensure accessibility, comprehensibility and usefulness of information. Vint Cerf stated it was essential that when transferring information from one location to another, it should be clear how to unpack it and to correctly interpret individual components. This requires ensuring that, in the distant future, the reading standards will continue to be known, and will allow the digital snapshot to be interpreted. The structure of information in the snapshot needs to be standardised and still known, or at least accessible and understandable, in order to enable its use and ensure data migration given the assumption of constant technological progress [Kosciejew 2015].

The first tests on Digital Vellum have already been conducted. According to Ian Sample, researchers from Carnegie Mellon University take digital snapshots of old computer hard drives while working with various programs. These are then transferred onto a new computer which can “imitate the snapshotted one” and read the files. Scientists have managed to “resurrect” e.g. an early version of Mystery House (an adventure game for the Apple II of the 1980’s as well as the game Doom. Work on the Digital Vellum concept and its practical applications is underway [Kosciejew 2015].

Not only does Digital Vellum involve technical issues but also, or primarily, economic and legal ones. It is not necessarily a commercially viable project, and its further development requires the commitment of financial resources and technological investments. There are few business incentives to develop this concept, and the legal conditions are not conducive to this either. The availability of most digital data is restricted by, *inter alia*, copyright, patents, licenses and other rights. The costs of buying the rights may be exorbitant or prohibitive. This is why Vint Cerf appealed for copyright, licenses and patent law to enable the preservation of software and make it available to future generations [Kosciejew 2015].

The term ‘digital vellum’ appeared much earlier than the Vint Cerf’s concept, e.g. in a paper by Terry Kuny, although in a slightly less technological context. Kuny [1998] pointed out as early as a couple of dozen years ago that despite the lack of public interest in the protection of digital resources, it is to be hoped that archivists’ efforts taken in this regard will be appreciated in the future. The data from digital vellum that can be saved will be a valuable source of information for future generations. Even though the task of digital resource protection is, indeed, unrewarding, it is necessary and needs to be undertaken. The aim is both noble and essential, even though many problems appear to be difficult to solve.

Summary

In many places worldwide, pioneering technical equipment is being reconstructed. There is a growing interest in retro computers. Therefore, it seems reasonable to include the native products of engineering thought in “museological” activities, as it is now increasingly difficult to obtain not only material exhibits but also their technical documentation.

Digitisation of archival materials supports the performance of tasks associated with the sharing and protection of cultural heritage objects. It implements the concept of open archives which offer a remote access to information, and the preservation of these materials for future generations. Digitisation allows archives to be widely opened and the oldest and most valuable analogue materials to be brought to light, which has so far been impossible, mainly due to the poor state of their preservation.

Digitisation of cultural heritage objects is perceived as an important area of activities aimed to preserve the cultural identity of a specific community. It is intended to protect original objects and to preserve their contents while increasing their accessibility. It also promotes the dissemination of knowledge, enables the use of materials previously missing in educational messages, and allows collections to be popularised. Mass digitisation programs facilitate the use of historical collections that are hardly accessible or completely inaccessible. Digital representations allow one to get to know the original better, and can be placed in a database which is usually easy to browse through. Modern technologies enable the creation of faithful surrogates. They also offer an opportunity to carry out innovative analyses that would not be feasible in relation to the original.

The presentation of cultural heritage objects on the Internet takes on a wide variety of forms, from classical digitised documents to three-dimensional models. A certain threat to the collections stored and shared in this way is the phenomenon of software and hardware ageing that results in the need to transfer, migrate

or emulate digital data, which can be complicated and costly. The development of computer software and hardware has been progressing rapidly, which has an effect on the lifetime of Internet forms of digital object presentation. Some of them become obsolete, are no longer modernised and expanded, and, in a specific way, they “wither away”. An example could be the online “Catalogue of monuments of Dutch colonisation in Poland”, which currently has an archaic form, and the latest update was introduced to it on 30 November 2009. Initiatives to share cultural heritage resources on the Internet should therefore be planned in the long term while taking account of changes in both software and hardware. However, this will certainly not stop the specific expansion of new technologies in the protection and dissemination of cultural heritage.

Laser scanning technology is more and more frequently used in museum management. This is one of the most effective methods for creating faithful surrogates. In recent years, many projects that involve scanning historic objects for both documentary and analytical purposes have been implemented [Cignoni and Scopigno 2008]. They have shown that the combined application of 3D scanning and 3D printing technology enables the construction of replicas without using traditional plaster castings that are too invasive, in particular for precious or fragile artifacts [Scopigno et al. 2015].

The biggest technical problems associated with the preservation of digital collections are due to physical deterioration of carriers on which data are stored, the ageing of formats, increasing software complexity and the restricted access to a set of files. As multimedia storage formats grow older, the bit rot phenomenon intensifies. However, every part of the code is necessary for the program to operate properly. Even minor disintegration of data may render a file unreadable. Another serious obstacle to the preservation of digital artifacts is copyright. Many archives contain only demo versions or program sections. This is particularly true for video games. Their creators defend intellectual property with great determination, and the efforts aimed at combating illegal copying may result in restrictions on access to games, even in order to preserve them for future generations. Due to copyright-based restrictions, many a collection of the highest research and educational value has not been made available on the Internet. It already happened in the past that the archive that published games was forced to withdraw the resources they made available and wait for the copyright to expire.

The selection of what will be classified as significant cultural heritage to be preserved can be more problematic than both the archiving itself and ensuring the accessibility of digital collections. Cultural heritage is what modern society chooses from the past to pass on to future generations. Many digital collections comprise subjectively selected games and programs which, as archivists believe, deserve to be regarded as “breakthrough” in a particular era. Who controls the past, controls the future. Who controls the present, controls the past (George Orwell, "Nineteen Eighty-Four", 1949). Lyons [2016] drew attention to the questions which, according to the archivist community, are currently more burning than bit loss, namely: what deserves to be regarded as digital cultural heritage and, thus, to be preserved? Who is competent to decide what will be archived and based on what criteria? These questions have not been clearly answered to this day.

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