Presenting the invisible and unfathomable: Virtual museum and augmented reality of the Neolithic site in Bylany, Czech Republic

Jak představit, co je neviditelné a neuchopitelné? Virtuální museum a rozšířená realita neolitické lokality v Bylanech

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The aim of the article is to demonstrate the possibility of presentation of prehistoric sites in locations where there is neither any preserved construction, nor any relic of the original landscape. Such sites usually meet with indifference both from the public and from institutions involved in preservation of historical monuments. This problem, however, does not relate only to the limited capacity to imagine features of which there is no visual evidence in the landscape. The problem consists also in the vast structural difference between the world of prehistoric societies and today's reality. Bylany near Kutná Hora (Czech Republic), where one of the most important excavations of a Neolithic settlement area in Europe was undertaken, represents a model example of such a situation, no doubt typical for most prehistoric and early historic sites. The possibility of creating virtual and augmented reality proved to be a potential tool to grasp the invisible and to describe the disappeared proved to be. This concept represents a potentially powerful tool for digital heritage management.

digital heritage management – virtual museum – augmented reality – Neolithic – community engagement

Cílem článku je ukázat možnosti prezentace prehistorických lokalit, a to na místech, kde se nedochovaly viditelné památky ani původní krajinný ráz. Taková místa jsou obvykle stranou zájmu, jak veřejnosti, tak institucionalizované památkové péče. Daný problém přitom nesouvisí pouze s omezenou schopností představit si objekty, které už v současné krajině neexistují. Jde také o potíž s obsáhlou strukturální rozdílností mezi světem prehistorických společností a realitou současnosti. Modelovým příkladem takové situace, jinak standardního stavu absolutní většiny prehistorických a raně historických lokalit, jsou Bylany u Kutné Hory, kde proběhly jedny z nejdůležitějších vykopávek neolitického sídliště v Evropě. Jako možné řešení toho, jak uchopit neviditelné a popsat zmizelé, se ukázalo využití možností virtuální a tzv. rozšířené (augmented) reality. Koncept představuje potenciálně silný nástroj digitální popularizace a památkové péče.

digitální památková péče – virtuální muzeum – rozšířená realita – neolit – zaujetí místních obyvatel

Introduction

The main problem encountered in regard to the presentation of the sites of Central European prehistory is their invisibility. Let's "visualise" this at several important sites dated to the Neolithic period. If a person happens to come to Eythra (Saxony, Germany), Herxheim (Rhineland-Palatinate, Germany), Těšetice (Moravia, Czech Republic) or Bylany (Bohemia, Czech Republic), where the vast residential areas of the first European farmers (5600–4400 cal BC) are buried under layers of earth he or she will pass over them, without noticing. The only tangible evidence of the existence of these exceptional sites are some ploughed-up fragments of Neolithic artifacts (*fig. 1*). Nonetheless, each of the sites mentioned has in its

Fig. 1. An agricultural landscape in Central Bohemia and in fact one of the most important sites of the Neolithic culture in temperate Europe: Bylany, Czech Republic.
Obr. 1. Fotografie zemědělské krajiny středních Čech je ve skutečnosti pohledem na jednu z nejdůležitějších neolitických lokalit evropského mírného pásu: Bylany u Kutné Hory.

own way significantly altered the perception of the world of the first European farmers. Wooden water wells from Eythra (e.g. *Stäuble – Hiller 1998*; *Tegel et al. 2012*), ditch enclosure with enormous number of human skeletal remains at Herxheim (e.g. *Wild et al. 2004*; *Orschiedt – Haidle 2012*), circle wall enclosure at Tešetice (*Podborský 1988*) or long-term Neolithic settlement agglomeration in Bylany (e.g. *Soudský 1962*; *Pavlů 2010*) are the fascinating evidence of remote unwritten history of human culture.

The examples of Neolithic settlement are not exceptional in this respect. With some exceptions, remains of prehistoric settlements of Central Europe are essentially invisible in the landscape. This fact represents a considerable handicap in comparison with many other parts of Europe, where megalithic structures, giant earthen barrows and enclosed fields are still in existence. And this without mentioning sites where Roman aqueducts still carry water and where the presence of stone statues and monuments evokes memories of characters from ancient mythology. In Central Europe, visitors do not frequently have the opportunity of direct contact with witnesses of unwritten history. For these reasons both public archaeology and heritage management occupy a more uncertain position. Reconstruction, imagination and dragging into prehistory have so far been the domain of “bricks and mortar” museums, which, however, seek visitors only from within a limited target group (*Květina – Končelová 2013a*).

However, the very rapid development of information technology, the accessibility of the Internet and the overwhelming scale of the adoption of computer technology in recent years have created room for a change. One way is through the rapid expansion of “virtual museums” that transmit the content of “classic” exhibitions on the Internet. This, however, may well not be the real endgame in regard to the virtualisation of archaeological heritage management. The concept of virtual and augmented reality is very easy to apply at reconstruction of movable or immovable prehistoric artefacts and monuments. This concept enables the assignment of metadata information of textual, visual or spatial character to existing objects, and displaying them on commonly used portable electronic devices. In certain sense it is possible to create a parallel virtual "heritage" layer within the analogue reality (the real world). Such an approach is described here, the example being the presentation of the Neolithic site at Bylany (Czech Republic).

The roots of the society in which we are living today are associated with major economic change that transformed the very essence of the human societies that existed then (*Childe 1957*). This transformation that was initiated in the Near East ca. 9500 BC did not cross the imaginary threshold of Central Europe until several millennia later, when the first Neolithic cultural communities were established here within the range of ca. 5600/5500 cal BC (*Gkiasta et al. 2003*; *Zvelebil 2004*). Defined in brief, the inception of the Neolithic period was marked by the reorientation of the means of subsistence from the exploitation of wild natural resources obtained by means of hunting and gathering to growing crops and farming animals (*Price 2000*). Regardless of whether this change occurred quickly or slowly, through domestic or external stimuli, through acculturation or colonisation – its result was a totally new form of cultural environment. The oldest agricultural population of Central, and partly also Western Europe, is linked archaeologically to the Linear Pottery Culture (LBK) which covers the 5600–5000 cal BC period. The subsequent settlement phase is characterised as the Stroke Pottery Culture (SBK) that covers the 5000–4400 cal BC period.

In terms of archaeology and of site preservation, the Neolithic transition in Central Europe translated into a relatively dense network of sites. Each comprises a palimpsest of pits which through their formal and spatial relationships allow decrypting the ground plans of longhouses (wooden timber structures with wattle and daub walls). Other pits, both large (covering dozens of square metres), and small, existed mainly as extended pits that lined the west and the east walls of the original structures. Extremely large pits without any direct spatial relationship to these structures contained a mixture of artifacts which apparently belonged to an extended chronological interval (perhaps as long as 500 years). In contrast, the long pits located closer to the houses contained objects dating to substantially shorter time-intervals (*Květina – Končelová 2013b*).

In terms of the size of the area investigated and of the duration of the project, one of the largest Neolithic field-projects has been carried out since the 1950s in Bylany, near Kutná Hora in the Czech Republic (*Pavlů et al. 1986*). Although many large LBK settlements have been excavated (e.g. Eythra, Olszanica, Langweiler 8, Ulm-Eggingen), the importance of the Bylany project resides in its pioneering nature, its scale and its longevity, with the excavations and their analysis spanning a period of more than 50 years. The field activities and the subsequent processing of the objects found have been a source of numerous studies that have had a significant impact on the excavation methodology utilised at Neolithic sites and on the analysis of archaeological material originating from the first identified farmers in Central Europe. Bylany comprises a series of Neolithic settlements, 'micro-areas', that lie in the valley of the Bylanka stream, located on a fertile brown chernozem soil on a loess base. In addition to the LBK settlement, remains of a late phase of SBK culture have also been excavated in the same area. The sacred component, including several circle wall enclosures (rondels, Kreisgrabenanlagen), are dated to the SBK period. A nearby bi-ritual (inhumation and cremation) cemetery from the same period has also been excavated. The fortified hill-top sites of Cimburk and Denemark, dating to the Chalcolithic/Eneolithic (4500/4400–2300/2200 BC) period, have also been excavated (*Květina et al. 2012*).

For a long period public relations have been undervalued by the Bylany Neolithic project. This deficiency is reflected both in the public's awareness of the Bylany site and of the first farmers' culture, and the local community's attitude towards the site in terms of heritage protection on one hand, and its potential for tourism on the other. The public has no access to the results of the long-term Neolithic research nor to the archaeological artifacts, despite the fact that the local community was strongly attached emotionally to the site during the heyday of the fieldwork from the 1950s to the 1970s. This relationship has been lost to the degree that neither the local land-owners nor the local government are willing to integrate the site into the regional network of heritage sites.

In order to reverse this situation, a project entitled Archaeological 3D Virtual Museum: New Technologies in the Documentation and Presentation of a Neolithic Settlement has been conceived and has gained the support of the Czech Ministry of Culture. Following a digital heritage-management approach, the goal of the project is to create a virtual Internet museum that will present the Neolithic culture in central Europe using the settlements at Bylany as an example. The purpose of the project is to strengthen local community involvement and to emphasise the worldwide importance of the site and of the information that the long-term fieldwork research has yielded (*fig. 2*).

Methods of dematerialisation as the first step towards a virtual museum

The technological objective of the project is to represent the prehistoric realities of the Neolithic Culture and imaging them in a three-dimensional virtual environment. This objective necessitates two different methodological approaches. The first is transposing the movable artifacts (e.g. the pottery, lithics, grinding tools…) and then the immovable artifacts (such ground objects as pits, postholes, ditches…) into a virtual 3D format, while the second is the computer modelling of the immovable structures (houses, earthen enclosures) and their subsequent reconstruction. The method of optical scanning was primarily utilised for dematerialising the movable artifacts while 3D photogrammetry and 3D virtual modelling were applied at the immovable artifacts. We then decided to present the data obtained in both PC environment and in applications designed for mobile devices.

Optical 3D scanning

The basic technology for the virtualisation of artifacts is optical 3D scanning, the advantage of which is its capacity to capture an absolutely true-to-life virtual spatial model of the object (*Bruno et al. 2010*). In addition, this method also supports various final formats for recording, thesauration and the presentation of objects in digital form.

Although 3D scanning was introduced into archaeology a relatively long time ago, it has only recently become a crucial feature of many varied projects (e.g. *Neiss – Sabrina –*

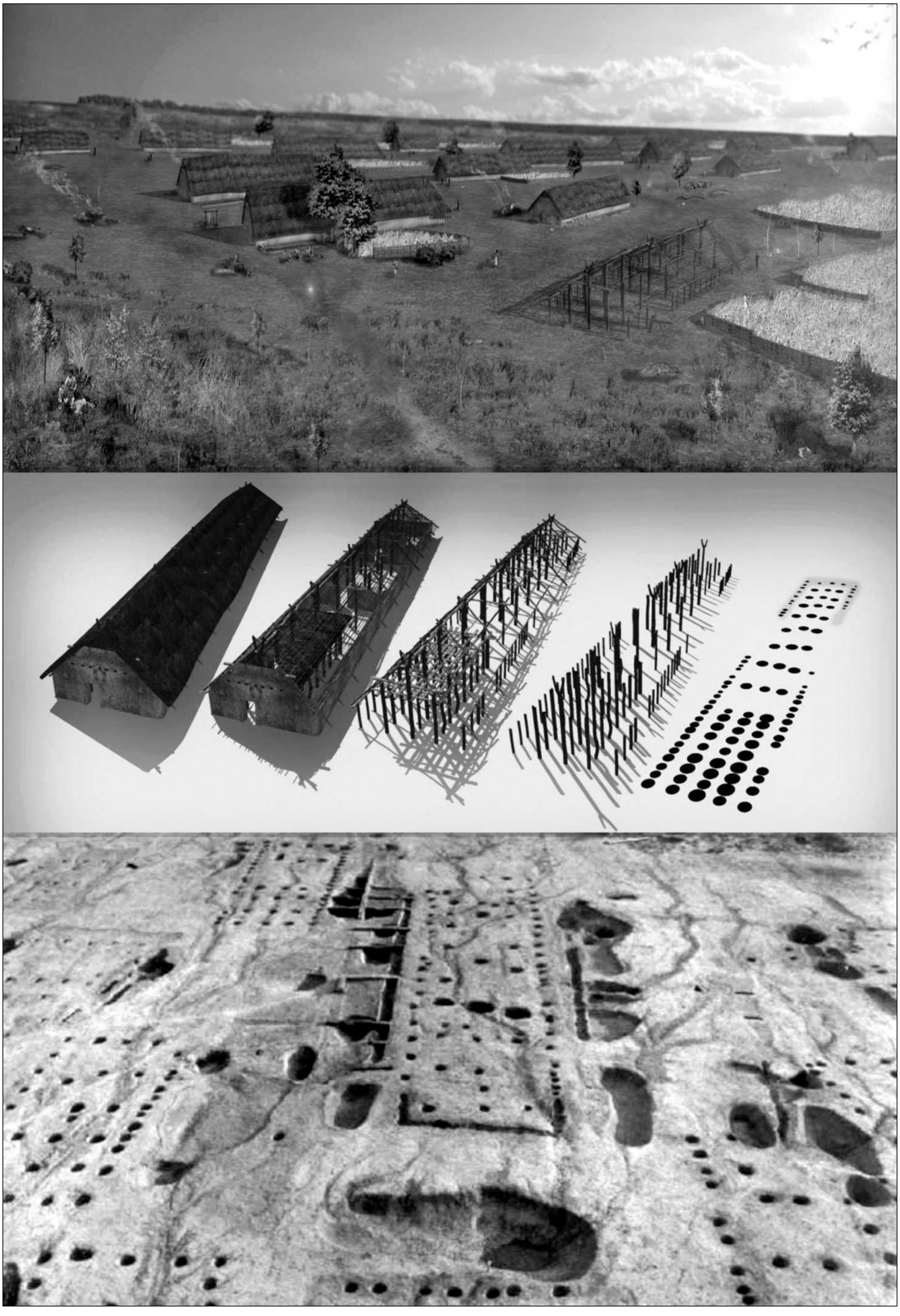

Fig. 2. A view of the Bylany site during the archaeological excavations, in comparison with a 3D virtual model of a Neolithic settlement.
Obr. 2. Pohled na lokalitu Bylany v průběhu terénního archeologického výzkumu a srovnání s 3D virtuálním modelem neolitického osídlení.

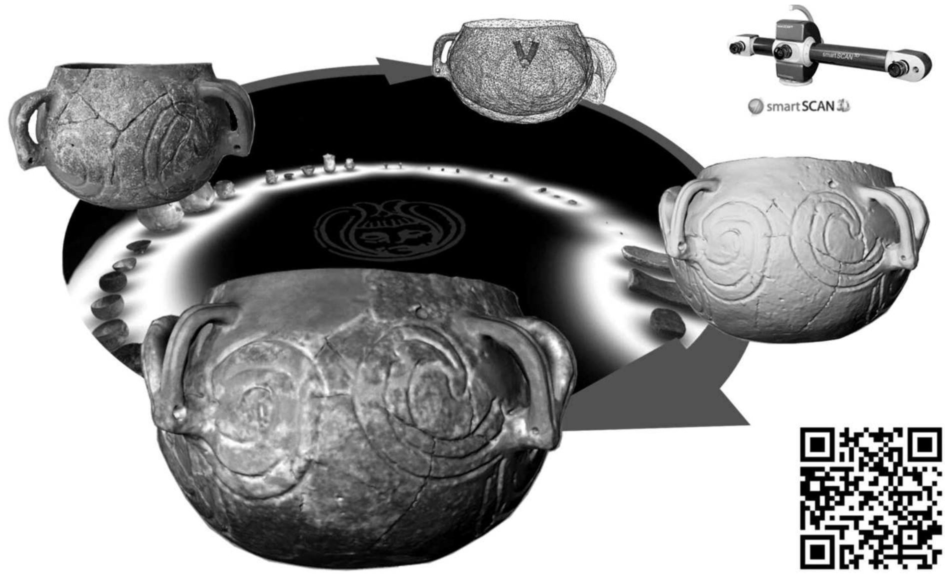

Fig. 3. The process of the dematerialisation of artifacts from Bylany site by 3D optical scanning. Virtual gallery of selected 3D scans for PC can be downloaded here: http://www.archaeo3d.com/archaeo3d_1.html
Obr. 3. Proces dematerializace artefaktů z Bylan založený na technologii optického 3D skenování. Aplikaci pro návštěvu virtuální expozice vybraných 3D skenů pro PC lze stáhnout zde: http://www.archaeo3d.com/archaeo3d_1.html

Wärmländer 2013; *McPherron – Gernat – Hublin 2009*; *Schulzen 2011*) and thanks to the development and the improvement of 3D scanning devices it is easy to obtain high quality outputs, a though the processing of fragmented raw data to generate a complete and usable 3D model still remains a complex task (*Tucci – Cini – Nobile 2011*).

Technologically the acquisition of information about shape and colour by means of optical scanning is ensured by the smartSCAN-3D scanner (Breuckmann, GmbH). This modular topometric system works on the basis of the banner projection of a sequence of stripes on the physical model and scanning the modified patterns using a high-resolution (5 megapixel) digital camera. Individual scans showing the surface of the object from different angles are subsequently merged into the resultant data object, defining both the comprehensive geometry and the texture of the scanned artifact. The high precision of the scanning of artifacts (which can be very variable in size) is ensured by the use of additional measuring ranges for the three fields of view from 60 to 300 mm (FOV S060, FOV M125, FOV M300). The system also includes software (OPTOCAT SW) that ensures the functioning of the digitising system during scanning, the automated merging of individual scans and the export of scanned data into various formats. Another sub-task, for the purposes of web presentation, is to reduce the file size to a fraction of its original size while retaining the complete visual information.

When searching for options for how to publish all the resulting 3D models of scanned artifacts we chose 3D PDF (*Felicismo et al. 2013*) because it is a widely supported format, which, though it does require module installation (*Adobe Acrobat Reader* or *Autodesk Design*

Review), on many computers this module is already pre-installed, or its installation can be automated. For direct display in the web browser (preferably Firefox), new cloud 3D platform Sketchfab (https://sketchfab.com/archaeo3d) was used. The platform enables basic interactive browsing of the 3D models (*fig. 3*). In case the user needs a more flexible way for examining the particular 3D scan, it is possible to download it in 3D PDF. This format enables more sophisticated ways of studying the scanned artifacts (including measurements, sections, lights and shadows options, etc.).

3D Photogrammetry

Another option for transferring physical archaeological objects into a virtual environment is the use of multi-image photogrammetry (*Harrower et al. 2014*; *Remondino 2014*). This method is utilised for processing three-dimensional images. In association with the appropriate software (e.g. Photomodeler, ImageMaster), this has enabled field archaeology to implement a completely new method for documenting immovable objects. The final step that enabled the mass utilisation of this method was the advent of online open source programmes in recent years (in particular 123D Catch or ARC 3D Webservice) that operate fully completely independently and do not require high degree of user knowledge. The new 3D photogrammetric programmes that are currently appearing on the market have a completely intuitive control system while the quality of the models created using them meets even the most demanding requirements (*Lo Brutto – Meli 2012*; *Santagati Inzerillo – Di Paola 2013*).

The undisputed positive feature of the methods of multi-image photogrammetry for the documentation of immovable features uncovered during archaeological excavations, is its modest financial demands, without any necessity for expensive equipment or trained personnel and, in particular, the rapid and easy acquisition of the necessary data (*De Reu et al. 2013*). The 3D model of a Bronze Age burial (*fig. 4*) was created using a freely available 123D Catch, and the 3D model of Neolithic burial, generated in the Agisoft Photoscan programme, was recreated from just 9 photos that were taken in the excavation (*fig. 4*).

3D Modelling

For the visualisation of immovable structures, computer manual 3D modelling was utilised because the development of graphics software together with the exponential improvement in the quality and the complexity of the models created using it, enables the creation of increasingly superior spatial reconstructions of selected objects (*Margueron – Gransard-Desmond 2012*; *Remondino – El-Hakim 2006*).

The method for creating 3D models includes importing of such 2D input data as floor plans and aerial photos or of 3D photogrammetric plans from archaeological excavations, to graphics programme such as Blender. This programme is an open source and provides a wide spectrum of modelling, lighting, UV-mapping, texturing, animation and video post-processing functionality.

Based on these plans, construction elements are modelled in these programmes and they are complemented by additional layers forming, for example, string walls, roofing and interior and exterior equipment, the textures of which are obtained from the Archaeological Institute's own photo library. The geographic information system (ESRI ArcGIS) is used for

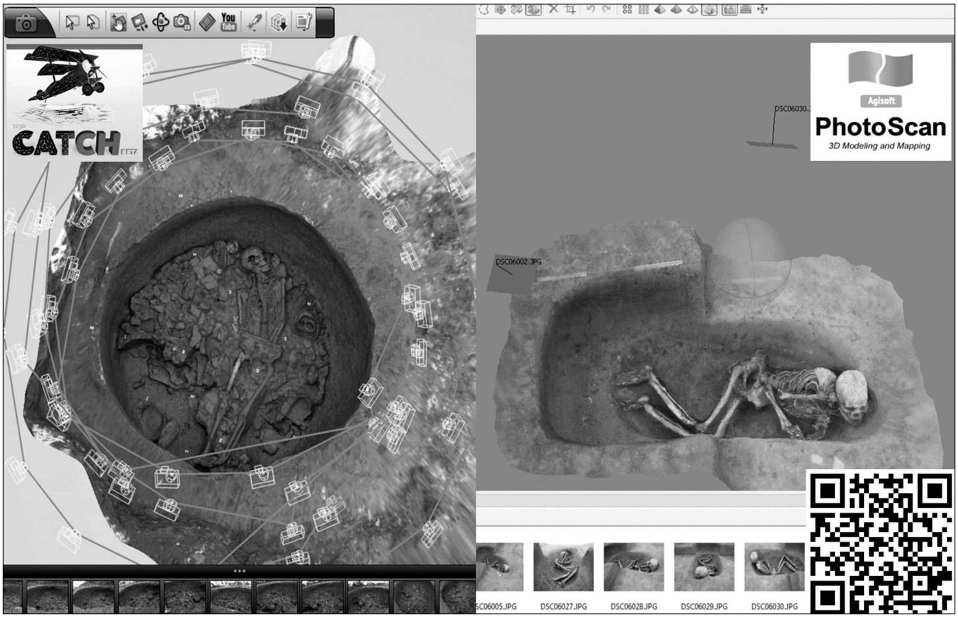

Fig. 4. Example of results from open source (123D Catch – Zálezlice site, burial from LBA period) and low cost (Agisoft Photoscan – Kolín site, Neolithic burial) 3D photogrammetric software: https://play.google.com/store/apps/details?id=com.virtualhistory.cave
Obr. 4. Ukázky výsledných modelů vytvořených v open source (123D Catch – lokalita Zálezlice, pohřeb z mladší doby bronzové) a nízko-nákladových (Agisoft Photoscan – lokalita Kolín, neolitický pohřeb) 3D fotogrammetrických programech: https://play.google.com/store/apps/details?id=com.virtualhistory.cave

locating 3D models of immovable structures in a real environment, one that also enables any required spatial analysis.

The output of 3D models can be implemented in the form of a static reconstruction, which in a graphic editor such as Photoshop, is accompanied by the appropriate vegetation, panorama and other visualisations, thereby creating a combination of vector and painted bitmap graphics. The final rendering, using colour filters, shadows and other graphic tools, is then implemented.

A second option for the output is the animation of immovable structures that is created by using scenes, which is a manner of simple displaying in different directions, accompanied by the gradual rendering of the individual layers for the complete animation of the individual parts, consistent with the construction sequence or its specific stages. The graphics and the sound editing, the cutting and the textual information included in the animation are provided by the Ashampoo Movie Studio 1.0.13 programme and the resulting output comprises video sequences in customary formats.

When processing data from archaeological excavations of Central European prehistory, 3D modelling represents an important tool for the presentation of the situations discovered and, in combination with the 3D photogrammetric models acquired in the field, it provides exactly the kind of information that is also understandable to the general public (*Guidi* –

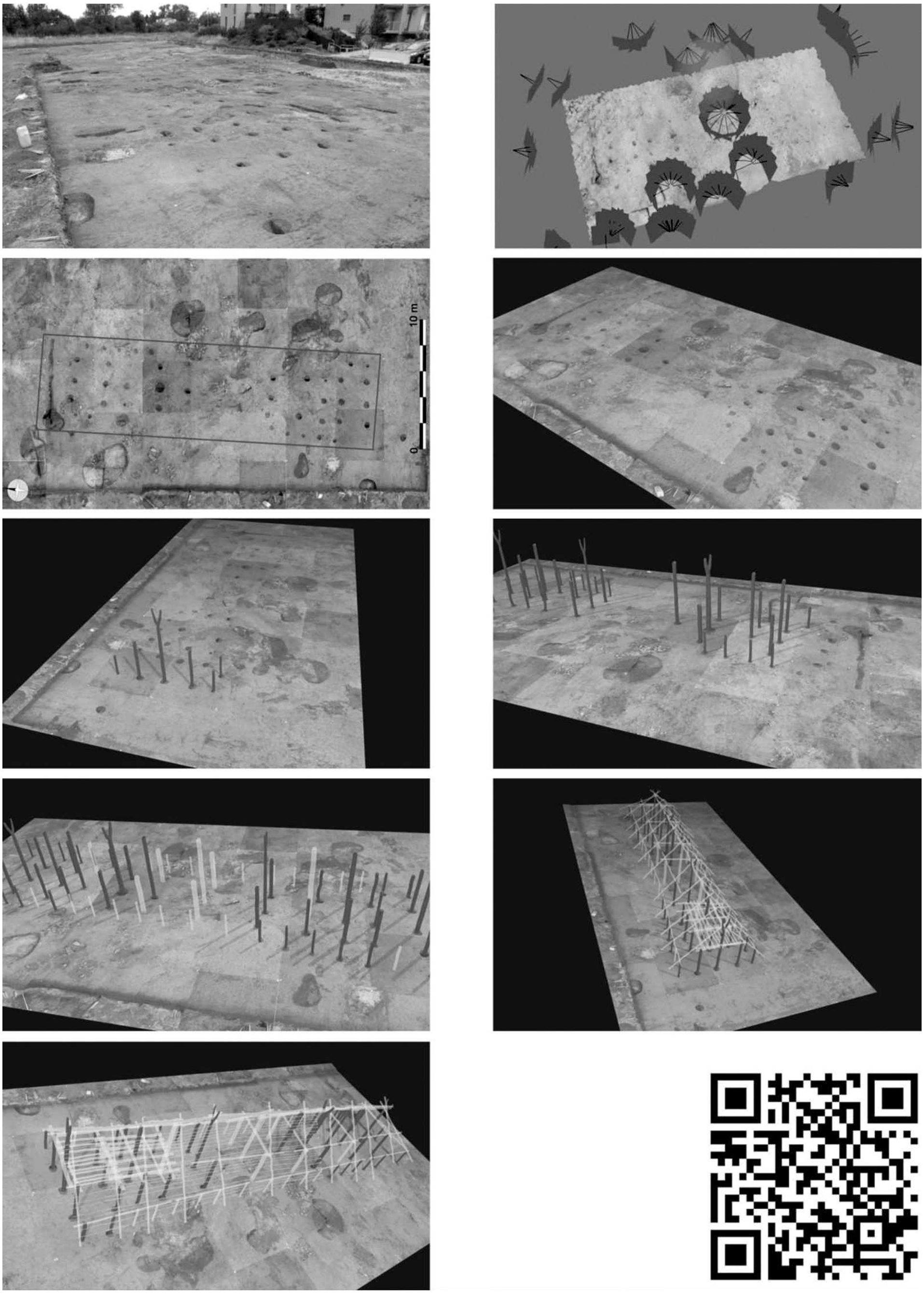

Fig. 5. LBK longhouse reconstructed directly in the field (site Prague-Vinoř, Czech Republic). Combination of 2D and 3D photogrammetry with 3D virtual modelling. Video available http://www.archaeo3d.com/archaeo3d_4.html

Obr. 5. Dlouhý dům LBK rekonstruovaný přímo v terénu (lokalita Praha-Vinoř). Kombinace 2D a 3D fotogrammetrie spolu s 3D virtuálním modelováním. Video dostupné zde: http://www.archaeo3d.com/archaeo3d_4.html

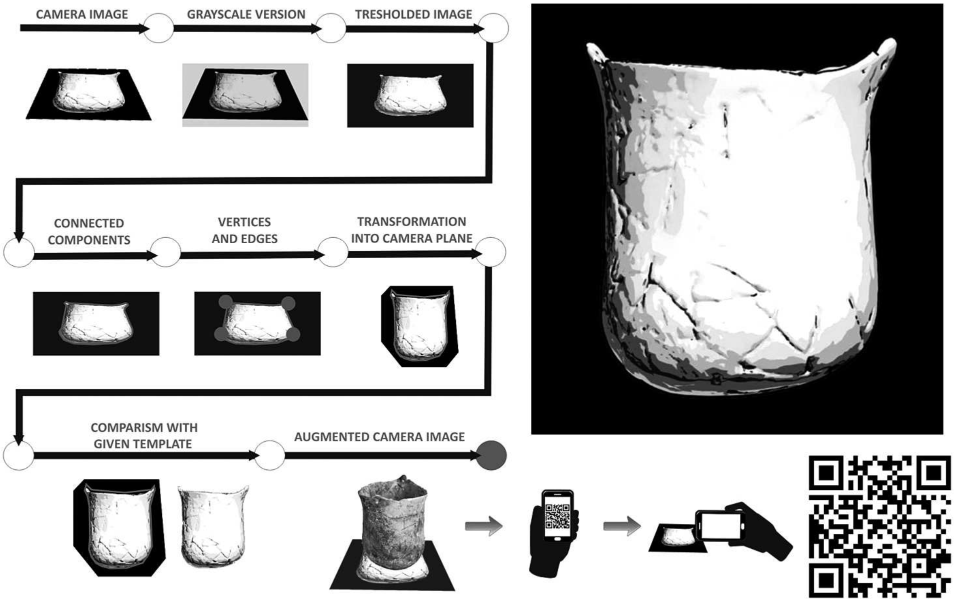

Fig. 6. General flow chart of a common augmented reality applications based on artificial markers (modified from *Procházka et al. 2011*). Augmented reality application available here: http://www.archaeo3d.com/archaeo3d_3.html
Obr. 6. Schéma zobrazující obecný princip aplikací rozšířené reality využívající umělého markeru (upraveno podle *Procházka et al. 2011*). Konkrétní aplikace rozšířené reality pro zařízení s OS Android ke stažení zde: http://www.archaeo3d.com/archaeo3d_3.html

Russo – Angheleddu 2014). *Figure 5* shows the 3D photogrammetric model of relics of the Neolithic longhouse of the Linear Pottery Culture that was captured in August 2014 during the ongoing rescue excavation implemented in Prague-Vinoř (Czech Republic). A 10 by 35 metres scene that was dominated by the structure of the longhouse consisting of the negative imprints of former posts and of adjacent loam pits was multiple photographed. It was then processed using the Agisoft Photoscan programme and after that a 3D terrain model was created. Subsequently a photographic texture of perpendicular single-image photogrammetric images was applied to this model that enabled the creation of a more comprehensive final-image output (*fig. 5*). Also comprising another possible outcome of these data are complete animations depicting, for example, individual structural elements in accordance with their construction chronology in the form of video sequences.

Virtual gallery

We decided to present the selected group of artifacts in the form of a virtual gallery, for which the principle of game engines was used; in this specific instance UDK from Epic Games, which was originally developed for the traditional first-person computer games. This form of software framework enables using either a keyboard and a mouse or a touch screen to change, according to one's own choice, either or both the route and the direction of a tour of the virtual environment. Its specific major advantage for the interactive 3D pre-

Fig. 7. Virtual tour of the Neolithic village reconstructed on the basis of archaeological research in Bylany. Demo version can be downloaded here: http://www.archaeo3d.com/archaeo3d_2.html
Obr. 7. Virtuální procházka neolitickou osadou rekonstruovanou na základě archeologického výzkumu v Bylanech. Demo-verzi lze stáhnout zde: http://www.archaeo3d.com/archaeo3d_2.html

sentation of computer data is its integration that combines such functions as rendering (a rendering engine for 2D and 3D graphics), artificial intelligence, networking, a physics engine or collision detection, localisation support and memory and therefore it can be utilised fairly easily for various types of virtual tours (*Anderson et al. 2009*; *Champion 2010*). In the virtual gallery presented there are 30 artifacts that are exhibited in this manner and that are divided in accordance with the material(s) from which they are made and also partially in accordance with their chronology and a visitor is able to move around them freely and to view the exhibits from every angle and perspective (http://www.archaeo3d.com/).

Augmented, virtual and mixed reality

As another output for the presentation of artifacts we chose an application from the Android operating system for mobile devices that utilises the principle of augmented reality. This designation is used when the depiction of reality is augmented by the inclusion of digital elements. For this application we used a system with a marker, which is a specific picture with which the application is familiar. In a scene that is viewed directly through the camera it attempts to locate this marker, to identify it and to determine its position and orientation within the scene (*fig. 6*). Based on the information that it receives on the display panel of the phone it then creates the desired 3D model, which is correctly positioned and oriented. This method of image-processing, based on the identification of artificial objects, greatly simplifies the processing of received data because the object is easily recognisable

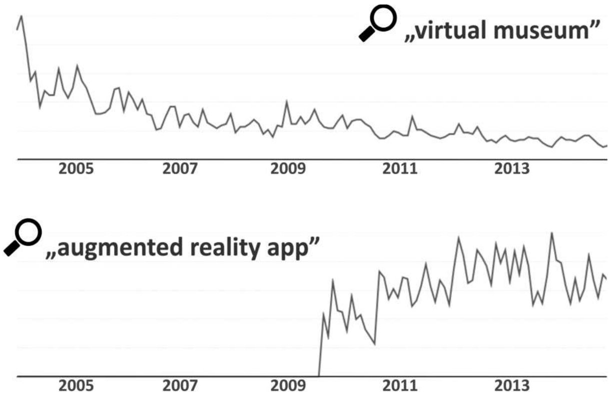

Fig. 8. Statistics of the search terms in Google between 2005 and 2014 suggests the potential of mobile applications with augmented reality for the presentation of cultural-historical heritage directly "on site".
Obr. 8. Statistika četnosti vyhledávání daných termínů v Google v rozmezí let 2005 a 2014 naznačuje posun zájmu směrem od statických virtuálních muzeí k interaktivním aplikacím rozšířené reality, které umožňují prezentaci kulturně-historického dědictví přímo v terénu.

in a scene and it was in this manner that the robust and fast algorithms that are used for these applications were developed (*Murru – Fratarcangeli – Empler 2012*).

For the presentation of 3D models of immovable structures, in addition to the classic formats (3D PDF, video sequences etc.), we also utilised the form of virtual reality (see *Barceló – Forte – Sanders eds. 2000*), based on the previously mentioned principle behind game engines. In this case Unity 3D, through which the models created in other 3D programmes can be imported directly, while the programme has a complete set of tools (script and animation), which allows the immediate building of a virtual system. The final product can be published on the Internet or, by using the Unity 3D Pro, it is possible to create a mobile application from it.

Our application simulates a virtual tour through part of the Neolithic village in Bylany, the 3D reconstruction of which was based on the findings of the archaeological excavations. The user can move freely through the selected area using the touch screen, while another option is to see this 3D model, which can be rotated and zoomed to present the detail (*Kotarba-Morley et al. in press*), from a bird's eye view. However, in order to facilitate the visitor's opportunity at the location of the monument to better understand and experience its 3D reconstruction, the gyro mode function was utilised for part of the application. After implementing this feature of the application, it is therefore possible to "set foot" right in the middle of this Neolithic village and, by moving the device sideways, to look all around it. Since the current form of the contemporary landscape has been incorporated in the model (*fig. 7*), this results in combining the virtual world, comprising 3D reconstructions of Neolithic dwellings, with the real world.

During the creation of a virtual web-museum we have increasingly felt the need for the more extensive use of mobile applications since the mass adoption of portable devices with such features as GPS, a compass, an accelerometer and/or a gyroscope opens-up a whole new dimension of options for presenting archaeological data.

This strong experience can be made available for visitors to sites by means of mixed reality (*Eve ed. 2014*), i.e. an application based on augmented reality, which, however, works without an auxiliary marker on the basis of an algorithm that teaches it to identify the real natural objects while, at the same time, also utilising the special method called SURF (Speeded Up Robust Features). The implementation of this method is still difficult for mobile

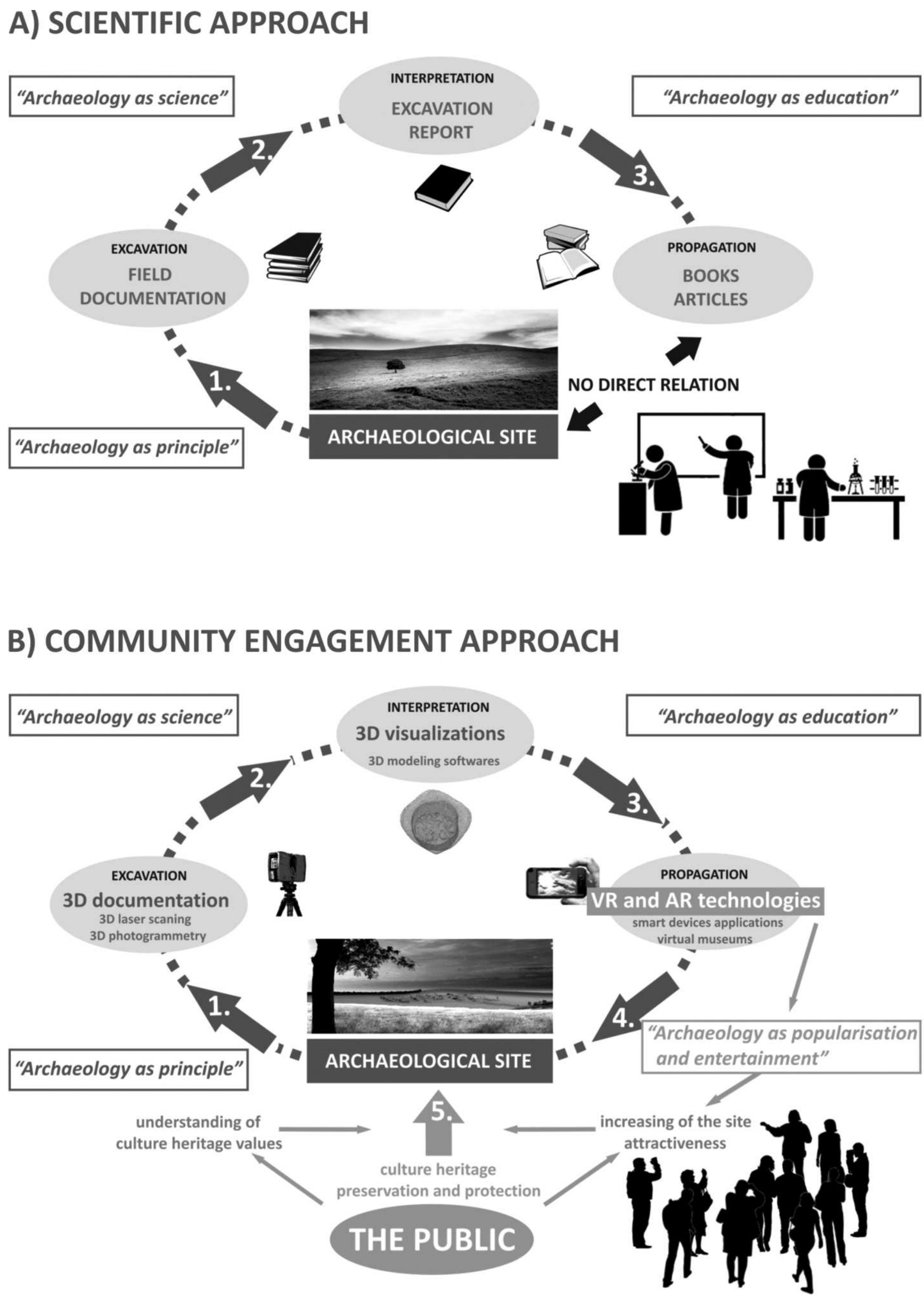

Fig. 9. By extending the standard presentation channels of archaeology to include the area of virtual space it is possible to greatly increase public interest in knowledge about and the protection of the archaeological heritage.

Obr. 9. Rozšířením standardních prezentačních mechanismů archeologie o virtuální prostor je možné zvětšit veřejné povědomí o významu archeologické památkovém péče.

devices (because of limited computation performance, memory, network connectivity, etc.) and at the locations of most prehistoric sites it is almost impossible. The absence of above-ground relics and the character of the Central European landscape require the utilisation of a hybrid method that, using a GPS and a compass, directs the visitor to a specific location and only then does the application start to search the area and to identify the objects learned to which it then applies a 3D model reconstruction of the archaeological object(s) within the real environment.

If, however, as is the case of Bylany near Kutná Hora, the visitor is in the middle of a flat open field, this method cannot be used and we had to choose a compromise solution, whereby, while it runs the above application using the gyroscope, the application navigates the person to the site of the discovery and where the real landscape is incorporated directly into a 3D model of the Neolithic village. Mostly it is not even possible to consider the construction of an artificially created auxiliary marker defining the design plan of, for example, one of the longhouses, because, in these places, usually either intense agricultural activity is implemented or it is heavily wooded countryside. If we resign to being present at exactly the given site, which, for differing reasons, is either inaccessible or unattractive, another possibility may be to combine information panels located close by with the AR/VR applications, whereby the panel can substitute directly for the marker, or the marker may be embedded in front of it as a walk board, for example.

Conclusions

The generalised problem with the on-site presentation and the heritage management of Neolithic sites comes from their standard preservation pattern. Most of the information concerning the imagery of the culture of the first Central-European farmers comes from the pits. In terms of simplified typology we can discern small, large and extremely large pits; nothing else. No standing houses, shrines, defensives walls or other structures are preserved. This represents a real challenge, both in terms of its presentation and in regard to overall public awareness concerning the necessity of the preservation of archaeological monuments.

We have dedicated our work to the issues of the public visibility and the presentation of the sites of Central European prehistory. A parallel aspect, however, is also the lack of public awareness of the tangible unwritten evidence about this period of human history either in the form of movable or immovable objects (landscape sites). One of the current options for how to at least partially address heritage management at this level is the utilisation of mobile applications. The mass adoption of smart phones brings with it a whole new range of options for presenting archaeological data. The combination of the real and the virtual worlds, easily accessible through the telephone's display, enables leaving the PC monitor behind, and presents a unique opportunity to enjoy the knowledge retrievable at archaeological sites directly in the field (*fig. 8*; *Gongli – Jin – Huilian 2013*; *Noh – Sunar – Pan 2009*; *Stuart 2012*).

We aimed to demonstrate that it is possible to implement the virtualisation of even those archaeological sites at which the fieldwork was carried out a long time ago and where there was no option to intentionally choose and collect the appropriate data. This is certainly a positive conclusion because it means that it is possible in this manner to at least partially process and also present such sites, the importance of which has been obvious to the archaeological community for several decades, whereas most of the rest of the population still has no concept of them. It is even more important, during the current implementation of archaeological research, to make use of the options provided by virtual archaeology, whereby it is possible, directly in the field, by utilising free or low-cost and easy handled 3D tools (such as 3D photogrammetry; see *Campana – Remondino 2008*) to instantly acquire a database of information that can later be used for the overall transformation of the data into a virtual environment. Adherence to these principles, also within the context of rescue excavations, the results of which usually end up only as reports found in the archives of the relevant institutions, will enable their quick and easy presentation to the public through virtual space, which in turn will immediately shift the motives for rescue excavations to another level.

Therefore the overall purpose of the entire project is its targeted focusing on public archaeology. One difficult reality is that cognition of the oldest, even pre-literary history of human culture remains within the closed professional academic and heritage management circles (*fig. 9*). Therefore no direct relation exists between the sites and either the general public or the local community. Thereby any effort to provide virtual access to the site represents an alternative and desirable approach. It would provide an easy and enjoyable way to obtain information and to experience the local genus loci (*Fritz – Susperegui – Linaza 2005*; *Kounavis – Kasimati – Zanavi 2012*). It will also help to break down the barrier between the public and archaeology as either a science or one of the humanities. The goal is to engage the public and for this to lead to an understanding of the value of our cultural and our historical heritage (*fig. 9*; *Roussou 2002*; *Tan – Rahaman 2009*; *Rahaman – Tan 2011*).

Modern technologies essentially handed over to archaeology the keys to the gate, through which it is possible to enter into alternative worlds of the past. For public archaeology, which is understood as an interactive interface between distant past and public, the results of the current development can be very important. We suddenly acquired the ability to fully visualise and interactively present the result of our research at precisely the time when modern society slowly moves away from the media formats based on unilateral transmission of information. World Wide Web connects by its international network the entire world, in which the individual loses a deeper relationship with the place and the community where she or he lives. Virtual travel in time may be soon an available means of entertainment, in which it will be possible to simultaneously reassure diachronic and synchronic links of each individual with a depth of the past of his or her own country. The technologies presented can in this way largely influence the social memory of a nation, which is one of the most important parts of its inner identity.

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Jak představit, co je neviditelné a neuchopitelné? Virtuální museum a rozšířená realita neolitické lokality v Bylanech

Prezentace prehistorických lokalit středoevropského pravěku naráží především na problém jejich krajinné neviditelnosti a tak ocitne-li se člověk např. v Bylanech u Kutné Hory, kde leží pod nánosy zeminy pohřbené rozsáhlé sídelní areály prvních evropských zemědělců, projde nad nimi bez povšimnutí (*obr. 1*). V práci, která je jedním z výstupů projektu „Archeologické 3D virtuální muzeum. Nové technologie dokumentace a prezentace neolitického sídelního areálu", jsme se pokusili ukázat, že jednou z možností popularizace a zpřístupnění takových prehistorických lokalit je virtualizace archeologických dat samých a současně také interpretační imaginace, jež z nich vychází. Demonstrovali jsme, že to lze úspěšně provést i v případech, kdy terénní archeologický výzkum proběhl několik desetiletí nazpátek, a není tak žádná možnost intencionálně vybírat a shromažďovat vhodná data přímo v průběhu vykopávek (*obr. 2*). To je bezpochyby pozitivní zjištění, protože to znamená, že je možné tímto způsobem prezentovat i klasické lokality, jejichž význam je naprosto zřejmý archeologické obci, ale ne tak už laické veřejnosti.

Technologickým záměrem daného projektu je prezentovat zaniklé reálie neolitické kultury a jejich rekonstrukce v trojrozměrném virtuálním prostředí. Tento přístup vyžaduje dva metodicky odlišné přístupy. Prvním je převedení movitých artefaktů (keramických nádob, kamenné štípané a broušené industrie, zrnotěrek…) a nemovitých objektů (zahloubené objekty typu jam, kůlových jamek, příkopů…) do 3d virtuální podoby a druhým je počítačové modelování a rekonstrukce nemovitých struktur (domy, rondely, krajina…). Pro dematerializaci movitých artefaktů jsme použili především metodu optického skenování a pro nemovité byly použity techniky 3D fotogrametrie a 3D virtuálního modelování. Získaná data ve formě klasických 3D souborů, virtuálních tour a rozšířené reality jsou použitelná, jak v prostředí PC, tak i v aplikacích určených pro mobilní zařízení.

Primární technologií pro akvizici trojdimenzionálního zobrazení movitých archeologických nálezů je optické 3D skenovaní, jehož výhodou je schopnost zachytit naprosto věrný virtuální prostorový model objektu. To jednak vytváří nové bezbariérové možnosti prezentace, a jednak znásobuje potenciál jejich zachování pro případ, kdy je originál zničen. Skenování je prováděno prostřednictvím přístroje SmartSCAN 3D od společnosti Breuckmann (*obr. 3*). Virtuální trojrozměrný obraz předmětu je ve finále uložen v 3D formátu (.ply), který uchovává vedle tvaru i texturu originálu. Tyto polygonální modely představují relativně velké soubory a z tohoto důvodu nejsou vhodné pro přímou prezentaci. Pro tu se naopak hodí decimované kopie zpřístupňované pomocí vizualizačního plug-in ve formátu 3D PDF anebo na webu přímo v internetovém prohlížeči v rámci platformy Sktechfab. Obě možnosti se na straně uživatele obejdou bez instalace specializovaného softwaru (https://sketchfab.com/archaeo3d).

Vybrané artefakty jsme se rozhodli zpřístupnit také formou virtuální galerie, ve které byl využit princip herních enginů, v tomto případě konkrétně UDK od Epic Games, který byl původně vyvinut pro klasické počítačové hry z pohledu první osoby. Tento typ softwarové platformy umožňuje pomocí klávesnice a myši či dotykové obrazovky měnit dle vlastního výběru trasu a směr prohlídky ve virtuálním prostředí. Podstatnou výhodou pro interaktivní prezentaci 3D počítačových dat je především jejich

ucelenost. Ve virtuální galerii je tak vystaveno 30 artefaktů rozdělených dle materiálu a částečně i chronologie, ve které se může návštěvník svobodně pohybovat a prohlížet vystavené exponáty ze všech úhlů a náhledů (http://www.archaeo3d.com/).

Pro vizualizaci nemovitých struktur bylo využito standardní počítačové manuální 3D modelování. Nástup nových grafických aplikací a exponenciální růst kvality a komplexnosti modelů v nich tvořených, umožňuje provádět stále lepší prostorové rekonstrukce zvolených objektů. Metodou tvorby 3D modelů je import vstupních dat typu 2D půdorysných plánů, leteckých fotografií nebo 3D fotogrammetrických plánů z terénních archeologických výzkumů do zvolených grafických programů (např. SketchUp nebo Blender). Zde jsou na jejich základě modelovány konstrukční prvky, které jsou následně doplněné o další vrstvy tvořící např. výplet zdí, střešní krytinu, vnitřní a vnější vybavení. Textury jsou z větší částí získávány z fotobanky projektu. V rámci zasazení 3D modelů nemovitých struktur do reálného prostředí je využit geografický informační systém (Esri ArcGIS).

Výstup 3D modelu je realizován buď v podobě statické rekonstrukce, která je v bitmapových grafických editorech typu Photoshop doplněna vhodnou vegetací, panoramatem a dalšími vizualizacemi, a jedná se tak o kombinaci vektorové a malované bitmapové grafiky. Pomocí barevných filtrů, stínů a dalších grafických nástrojů je pak vytvořena finální vizualizace (*obr. 2*). Druhou možností výstupu je animace nemovitých struktur vytvořená pomocí tzv. scén, kdy se převážně jedná o formu pouhého snímání objektů v různých směrech doplněnou o postupné zobrazení jednotlivých konstrukčních vrstev.

Atraktivní možností využití 3D modelů nemovitých struktur je jejich prezentace formou virtuálních tour založených na již zmíněném principu herních enginů. Prezentovaná aplikace (*obr. 7*) tak umožňuje procházku částí neolitické vesnice v Bylanech u Kutné Hory, jejíž 3D rekonstrukce vznikla na základě poznatků archeologických výzkumů. Další z možností je prohlížení tohoto 3D modelu z pohledu ptačí perspektivy, kterým lze otáčet a přibližovat do detailů. Abychom na místě dané památky docílili možnost návštěvníkovi lépe pochopit a prožít její 3D vymodelovanou rekonstrukci, byla v rámci aplikace použita funkce gyroskop módu. Na předem daném místě, tak lze po spuštění této části aplikace „vkročit“ přímo doprostřed neolitické vesnice a pohybem přístroje do stran se po ní rozhlédnout. Vznikla tak kombinace virtuálního světa tvořeného 3D rekonstrukcemi neolitických obydlí a světa reálného, neboť do modelu byla zakomponována podoba skutečné dnešní krajiny.

Další z možností jak převést fyzické archeologické objekty do virtuálního prostředí je více-snímková fotogrammetrie, která slouží pro zpracování trojrozměrného obrazu (*obr. 4*). Tato metoda spolu s vhodným softwarem (např. Photomodeler, Imagemaster) umožnila terénní archeologii provádět téměř v reálném čase 3D dokumentaci nemovitých objektů. Posledním krokem umožňujícím masové využití této metody byl nástup on-line open source programů v posledních letech (především 123D Catch či ARC 3D Webservice), které pracují plně samostatně a nevyžadují sofistikovanější uživatelské znalosti. Nové 3D fotogrammetrické programy, které se nyní objevují na trhu (např. Agisoft Photoscan) pak již mají plně intuitivní ovládání a kvalita modelů v nich tvořených splňuje i náročné požadavky. Právě v tomto softwaru byl vytvořen 3D fotogrammetrický model (zkombinovaný s 2D fotogrammetrickými snímky) reliktů neolitického dlouhého domu kultury s lineární keramikou z lokality Praha-Vinoř (*obr. 5*). Možným výstupem těchto dat pak mohou být i kompletní animace zobrazující ve formě videosekvencí např. jednotlivé konstrukční prvky dle stavební posloupnosti.

Jednou ze zcela nových možností virtuálního zobrazování archeologických dat je využití mobilních aplikací. Současné masové rozšíření chytrých telefonů, které disponují větším výpočetním výkonem, než jaký byl zapotřebí k vyslání prvního člověka na Měsíc, totiž otevírá úplně nový prezentační rámec. Zatímco klasické PC formáty vycházejí z indoorové perspektivy uživatele, u mobilních zařízení lze zohlednit i jejich outdoorové použití, což může znamenat přímo v terénu archeologických lokalit. V aplikacích je pak možné kombinovat prvky reálného a virtuálního světa, které se na displeji zařízení vzájemně doplňují.

Pro potřeby projektu, který v textu představujeme, jsme využili variantu tzv. augmented reality, což je přístup na technologické bázi rozšířené reality. Aplikace přitom využívá systém tzv. markeru, což je specifický symbol (např. obrázek), na který je aplikace naučená a ve scéně zobrazované přes kameru se snaží tento marker vyhledat, rozpoznat a určit jeho orientaci a polohu v rámci snímané scény (*obr. 6*). Na základě těchto informací pak dokáže na displeji zařízení doplnit požadovaný 3D model, který je správně umístěný a orientovaný. Takovýto způsob zpracování obrazu výrazně zjednodušuje zpracování přijímaných dat, protože je tento objekt ve snímané scéně snadno čitelný (*obr. 8*).

Prezentovaný projekt cílí primárně na tematický okruh archeologie pro veřejnost (public archaeology). Tíživou realitou prezentace nejstarší či nezapsané (pre-literární) minulosti lidské kultury je totiž skutečnost, že její poznávání zůstává uzavřeno v profesním kruhu archeologické památkové péče a partikulárních vědeckých projektů (*obr. 9*). Proto až na výjimky nedochází k vytváření přímých vazeb mezi prehistorickými lokalitami na jedné straně a obecnou veřejností a lokálními obyvateli na straně druhé. Alternativní a podle našeho názoru žádoucí přístup proto představuje úsilí po (virtuálním) zpřístupnění lokality. To umožní snadnou a zábavnou formou čerpat informace a vnímat lokální genius loci. Odbourává se tím také bariéra mezi veřejností a archeologií jako čistou vědou. Cílem je přitom zainteresování veřejnosti, které by mělo vést k pochopení hodnot obecného i zcela konkrétního kulturně-historického dědictví.

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