3D VISUALISATION AND MULTIDISCIPLINARY ANALYTICAL TECHNIQUES ON CULTURAL HERITAGE OBJECTS FROM THE COLLECTION OF THE HUNGARIAN NATIONAL MUSEUM

3D MEGJELENÍTÉSI TECHNIKÁK ÉS LEHETSÉGES ARCHEOMETRIAI ALKALMAZÁSUK A MAGYAR NEMZETI MÚZEUM MŰTÁRGYAIN

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Abstract

3D visualisation techniques can serve archaeometric provenance studies by supporting non-destructive characterisation methods. In this paper, specific gravity measurements supported by 3D imaging techniques will be considered. The subject of analysis is so-called „greenstone" axes, all of them items of high prestige transported by long distance trade networks in prehistory. The 3D images obtained by (1) laser scanning (2) image matching methods help us fully document the artefacts and furthermore calculate the volume exactly. The advantages and drawbacks of these imaging techniques will be considered in respect of „greenstone" characterisation.

Kivonat

A 3D leképezési technikák, mint roncsolásmentes vizsgálati lehetőségek segíthetik az archeometriai célú származási-hely meghatározást. Tanulmányunkban a háromdimenziós képalkotási módszereket sűrűség meghatározásra használtuk. A vizsgálat tárgya néhány „zöldkő" balta volt, amelyek igen nagy távolságból kerültek Magyarország területére, különlegesen hosszú távú kereskedelmi láncolat eredményeképpen. A tárgyak igen nagy presztízs-értéket képviselnek, és ma is jelentős kulturális értékkel bírnak, ezért vizsgálatuk kizárólag roncsolásmentes módszerekkel végezhető. A kőzetek fontos fizikai jellemzője a sűrűség (fajsúly), ami a jadeit esetében meglehetősen magas érték, ezért meghatározása hasznos lehet a kőzet azonosításában. A sűrűség meghatározásához a tömeg és a térfogat pontos ismerete szükséges. A térfogat mérését először hagyományos módon, a vízkiszorítás mérésével (mérőhengerben) kíséreltük meg, de úgy tapasztaltuk, hogy ez az eljárás nem eléggé pontos a balták térfogatának mérésére. Ezért a térfogat meghatározására 3D képalkotási technikákat használtunk, úgymint (1) lézer szkennelést és (2) képillesztést, melyek segítségével az eszközök pontos modellje előállítható és térfogatuk kiszámítható. Bemutatjuk az alkalmazott képalkotási technikák előnyeit és hátrányait, elsősorban a „zöldkő" eszközök szempontjából.

KEYWORDS: 3D SCANNING, IMAGE MATCHING, SPECIFIC DENSITY, JADEITE

KULCSSZAVAK: 3D SCANNING, KÉPILLESZTÉS, SŰRŰSÉG, JADEIT

Introduction

Various objects of cultural heritage relevance from the collection of the Hungarian National Museum (HNM) were subjected to non-destructive analysis by nuclear and 3D imaging techniques. The main objective was to gather more information on the objects for presentation and characterisation studies (Schulze et al. 2010, Biró et al. 2011). After initial trials on objects ranging from stone artefacts, pottery, metal and composite objects, ranging from Palaeolithic to Early Mediaeval, the analyses concentrated on polished stone tools made of „greenstones". These items represent in Hungary prestigous objects of long-distance trade. It is imperative to preserve the objects' full integrity and at the same time gather all available information for characterisation. Analytical techniques applied comprise magnetic susceptibility (MS), prompt-gamma activatrion analysis (PGAA, for bulk chemical composition), electron microprobe analysis (EMPA) and Goebel-mirror X-ray diffraction for mineral phases (Szakmány et al. 2013).

Methods

One of the important and characteristic physical qualities of high-pressure metamorphites (jadeite, omphacite and eclogite) is their high specific density (Errera 2014). We were trying to measure this feature by traditional measuring cylinder, but the reproducibility of the measurement indicated that our accuracy is not adequate. With the availability of 3D imaging techniques, we were trying to calculate volume with great precision that helped us to definfe specific density of the pieces. The biggest obstacles in the way of the current project concerning data recording and 3D digital modelling: First of all, it is important to mention that we were short of both resources and time. On the other hand, it was difficult to gain access to the stone materials and the limited number of data recording occasions also caused problems. Besides, to protect the artefacts, a strict rule was laid down in the analysis of polished stone-axes: only non-destructive methods were allowed. Lastly, complying with the requirements of measurement, it was necessary for the outgoing formats of the models to be compatible with the CAD systems. As it was an important goal to work out a cost-efficient method that can later be applied to bigger quantities of items, in the project we have tried the laser scanning method, which can be considered traditional and is more and more available, and the more progressive matching method among the 3D object digitization methods. They must be, as a rule, non-destructive methods and must maintain compatibility with the CAD systems (Lin et al. 2010, Sumner & Riddle 2008, Grosman et al. 2008). The main components of the computer used in the project were an AMD Athlon II X 4 561 Quad-Core 3.00 Ghz processor, 8 GB RAM, ATI Radeon HD 5600 video card, 500 GB hard disc drive, and a 64-bit Windows 7 Ultimate operation system. For the 3D scanning and partly for generating the models, a NextEngine laser scanner was used. The scanner has a built-in digital camera, automated platen, focus setting options and an integrated 3D modelling software (ScanStudio HD). The set exactness of the scanner: 0.12 mm, speed of recording points 60.000 point/second. It is an easily available, compact, table-top scanner (e.g., Hermon et al. 2011, Slizewski & Semal 2009). A Canon EOS 70D type camera was used for matching. Its important characteristics are as follows: useful image points/complete number of image points: 20.20/20.90 Mpixel. Picture aspect ratio was 3:2. In this case two have been chosen from the picture element matching softwares based on digital photos: 123D Catch (Lo Brutto & Meli 2012) and 3DSOM Pro (Ciobanu et al. 2013).

123D Catch was chosen due to its compatibility with AutoCAD (which makes it possible for it to become widely available) and the fact that it was developed for Autodesk softwarebase. The software is currently in beta testing phase. 3DSOM Pro was chosen because it is easy to operate and it is the widely used digitizing software of the virtual store of the Hungarian National Museum. In the case of the matching method, although the base softwares (123D Catch, 3DSOM Pro) had different abilities, the editing work did not differ much. For the edition, a 3DsMax software was used in the matching method, whereas in the laser scanning method Mudbox and 3DsMax softwares were used. The detailed working process of the laser scanning method and that of the picture element matching method can be seen in **Fig. 1.**

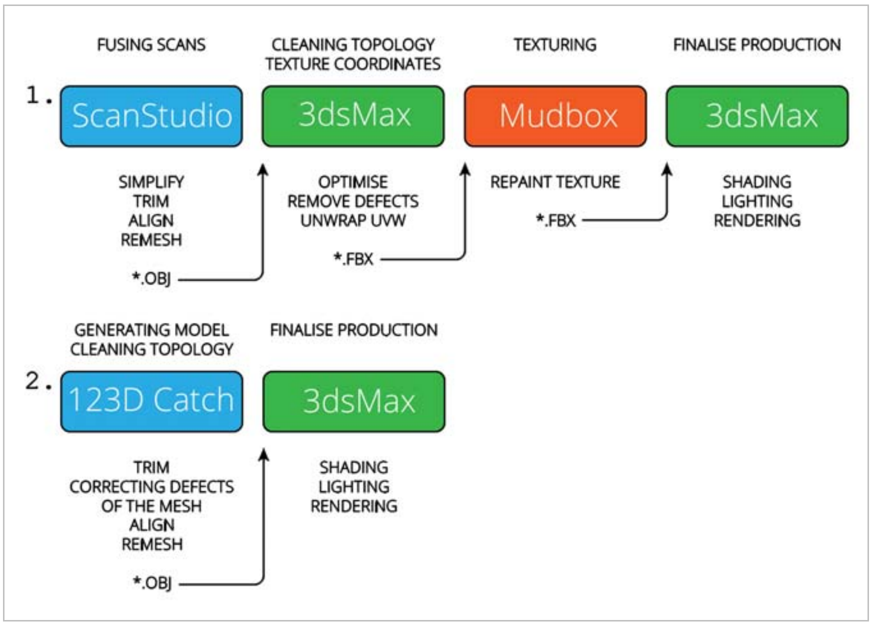

Fig. 1.: Work-flow chart of 3D laser scanning (1.) and 3D image matching (2.), respectively

1. ábra: 3D lézer szkennelés (1.) és a 3D képillesztés (2.) munkafolyamatának összehasonlítása

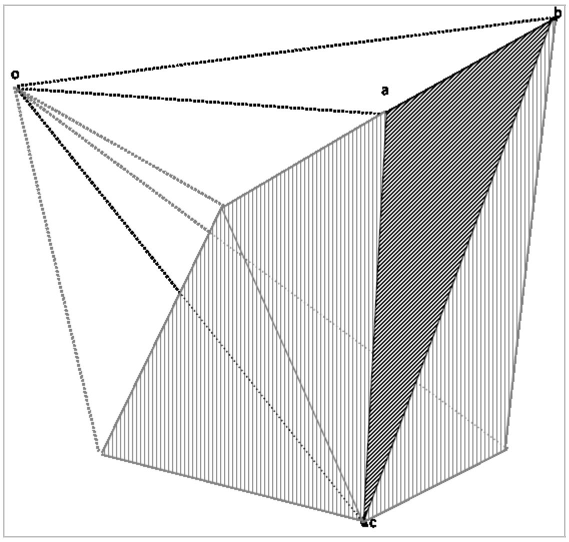

Fig. 2.: A tetrahedron, shown in black, formed by the a surface triangle (a-b-c, black crosshatch) and a reference point, e.g. the origin. Once its volume is calculated, the sum of these sub-volumes is a good approximation of the entire object volume

2. ábra: Egy tetraéder (feketével kiemelve), amelyet egy felületen lévő háromszög (a-b-c, feketével sraffozva) és egy referencia pont (pl.az origó) határoz meg. Az egyedi tetraéderek térfogatainak összegéből a tárgy teljes térfogata meghatározható.

The exact measurement of volume, on the basis of 3D imaging techniques, can be realised according to the following principles. The laser scanners result in a surface mesh of the scanned object. In this representation, the real surface of the object is approximated by a set of triangles (so called vertex). These are shown with cross-hatches in **Fig. 2**. If we select a reference point (usually the origin), and connect it with the corners of a triangle, we define a tetrahedron (**Fig. 2.**). For any complicated object, once approximated with such a triangular mesh, the volume is the sum of the sub-volumes of all tetrahedra bounded by the origin and a mesh triangle (shown in black; Obádovics 1994, Schuster 2008). This calculation can be generalized to cases where the object is not convex or does not contain the origin .

The market-leading laser scanner devices can capture fine details down to about 100 micron sizes. The NextEngine 3D Laser Scanner used in the present study stores the data in STL or OBJ formats that can be readily loaded to a CAD software (**Fig. 3.**). The CAD programs offer functionality to measure the linear extents of the object, and have the surface and volume calculation algorithms built in, so the user can obtain the physical features of a laser-scanned object in a quick and convenient way.

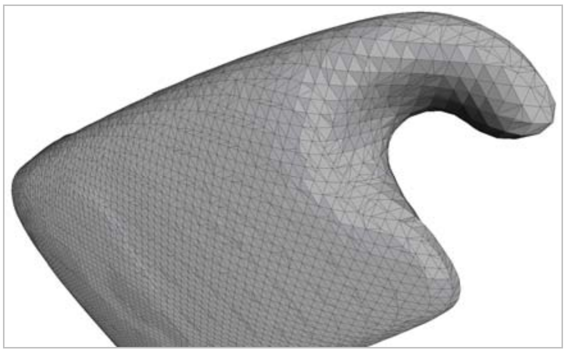

Fig 3. A coarse 3D digital representation of an object (Csót, HNM 300/876.431) where the triangular mesh was made visible

3. ábra: A tárgy (Csót, HNM 300/876.431) egy kisfelbontású 3D digitális modellje, amelyen a felületi hálót láthatóvá tettük.

Similarly, the center of gravity can also be defined, supposing the density of the material is constant over the entire volume.

Once the mass of the object is measured, the digital volume is calculated, the average density of the object under study can be obtained with a few percent precision. In contrast to the Archimedes' principle (buoyancy method), which states that a body immersed in a fluid apparently loses weight by an amount equal to the weight of the fluid it displaces, the proposed method allows the unbiased density determination not only for solids, but also porous objects or wooden objects. In the latter cases they can take up water and bias the result. The reliable density information offers a new possibility to classify the stone tools.

Results

There was a clearcut difference between the different object-digitizing methods (laser scanning or matching). The number of triangles in a mesh 3D model made by laser scanning is 81.000, whereas that for the matching is only 8800. The same difference was experienced in working hours too: here, the time required to record the data, to create and to visualise a 3D model (from the time the artefact was delivered) was 11 hours in the case of laser scanning, whereas in the case of matching (also from the time the artefact was delivered) it took 5 working hours (**Fig. 4a, Fig. 4b**).

In the partial summary below, which is focussed on the scientific and practical experiences concerning the analysed artefacts, it was not our aim to give a general theoretical description of the proven methods of digitization (laser scanning, picture element matching) in terms of their methodologies. Advantages and drawbacks of each methods are summarised in **Table 1.**

Table 1.: Advantages / drawbacks of 3D laser scanning and 3D image matching, respectively

1. táblázat: A 3D lézer szkennelés és a 3D képillesztési technikák előnyei és hátrányai

Laser scanning method (NextEngine laser scanner).		**Picture element matching method (123D Catch, 3DSOM Pro).**	
ADVANTAGES	DRAWBACKS	ADVANTAGES	DRAWBACKS
- The artefacts were suitable for the range of sensors and measure-ments and the automating possibilities of the scanner.	- Scanning reqired smooth and scattered lighting.	- The number of point data was enough, the 3D model could be handled easily with the software.	- There were 3D modelling errors due to the lighting phenomena connected to the exposure of the artefacts.
- Some digital surface flaws occured due to the light phenomena caused by minerals.	- It was difficult to record the real colour of dark surfaces.	- Digital photos projected the texture of the surface in great details.	- It is difficult for the matching process to filter the shades.
- The objects could be seen well: there are no holes, overlapping parts or bigger grooves.	- On the superficies of the artefacts there were only few identifying points.	- The picture element matching process gave a more real image of an artefact.	- Good quality recording required elements with strong contours and contrasts.
- The surface determiners of the polished stone-axes were easy to calculate with algorythms.	- When scanning, mistakes could be made with the correct recording sequence of the surfaces, the angle of exposure and the handling of covered parts.	- It was easy to make up for any lack of recorded data with photos of parts.	- In photos, only the focal point and its surrounding area were really clear.
- The projected cloud of points was differentiated and rich in details.	- Many points were recorded, which slowed down the process. The software of the scanner tended to treat the surface parts separately.	- To bring the 3D model into a showable condition required less and more simple editing.	- Sometimes, there were not enough matching points for orienting in close-up and high resolution photos.
- The surfaces of the objects had smooth texture.			- The background behind the objects considerably hindered the process of digitization.
			- The parts standing out of the surface did not differ from the whole of the digital 3D model, blurring with it. - Good texture covered the surface deficiencies of the 3D model. - The process was made more difficult by the fact that basically, the photos had to be taken in a given round-sequence. - Adding absolute sizes meant an extra process.

Table 2.: Results of density measurements obtained on the models of 'greenstone' axes by 3D Scanning and 3D image matching

2. táblázat: Sűrűség mérési eredmények a „zöldkő" baltákon 3D lézer szkenneléssel és 3D képillesztési technikával felvett modelleken

Inv.Nr	Locality	Dimensions (mm)	Mass (g)	Volume (mm^3)	Density (g/cm^3)	3D laser scan	3D DP photo	Rock type
MNM Ltsz: 51/1867.II.3	Belácz, Tolna megye	31*33*12.5	22.43	*8115*	*2.76*		*P1*	serpentinite?
VMM Ltsz: MIH.1276	Veszprém megye	97*50*19.5	150.61	**51073** *49898*	**2.95** 3.01	**G4**	*P2*	jadeitite
MNM Ltsz: 300/876.264	Bakonypéterd	57*33*12	30.49	**9216** *9356*	**3.31** *3.25*	**G3**	*P3*	jadeitite
MNM Ltsz: 300.870.247	Almásneszmély	40*32*10	26.99	**8497** *9122*	**3.17** *2.95*	**G2**	*P4*	iron-jadeitite
ELTE not yet inv.	MURSELLA beteen Árpád and Mórichida	42*25.5*9.7	17.45	*7647*	*2.28*		*P5*	serpentinite
MNM Ltsz: 300/876.431	Csót	40*26*8	19.51	**6744**	**2.89**	**G5**		greenschist / metabasite
MNM Ltsz: 300/876.83	Nyergesújfalu	102*61*20	228.94	**77560**	**2.95**	**G1**		greenschist / metabasite??

Fig 4. 3D digital representation of a greenstone axe
4. ábra: Zöldkő (jadeit) balta 3D modellje

Fig. 4a: by 3D laser scanning;
4a: lézer szkenneléssel

Fig. 4b: 3D image matching method
4b: képillesztéssel

The actual results of our density-measurements on the 'greenstone' axes are summarised in **Table 2.**

In case of two items (Bakonypéterd and Almásneszmély, respectively), we had the possibility to compare results of 3D scanning and 3D image matching on the identical object. It was realised that for the images made by 3D matching we have to apply an internal scale (typically, the longest dimension of the tool) for getting the correct starting point for the calculation of volume. Moreover, the number of points recorded is much higher for 3D scanning, thus the volumetry is more direct and more reliable.

Densitometry by the help of 3D imaging has become one of the powerful arguments of identifying greenstone axes.

The current status of jadeitite/omphacite axes are presented, using the base map of Pétrequin et al. 2011 (Fig.1.), with the location of recently identified items, on **Fig. 5.** More on the problem is presented in details by Bendő et al., this volume.

Conclusion

On the 3D object digitizing process based on the NextEngine laser scanner, the following conclusions can be drawn: The data of the points of the polished surfaces could easily be projected. At the same time, it was easy to spot any mistake made in recording the data. The 3D objects could be measured without texturing. The drawback of the method of digitizing artefacts with laser scanners is that it is slow and requires considerable resources and work. On the other hand, laser scanning is a proven, established process. In our case, it can be generally stated that their sizes, material characteristics and shapes made it easy to digitize the artefacts.

The possibilities of the used picture element matching process could be defined from the aspect of the current project in comparison with the laser scanning method.

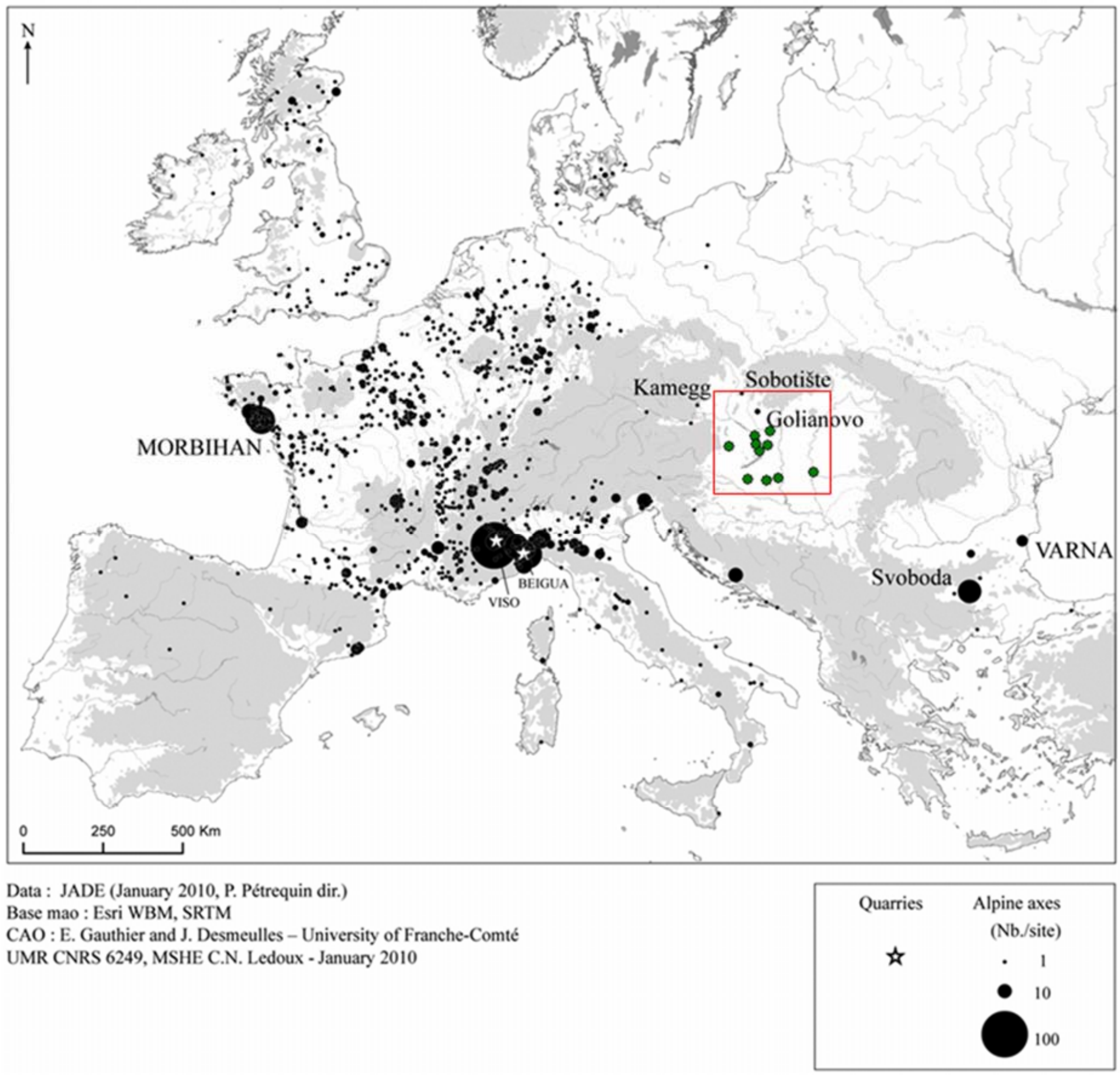

Fig 5. Map of jadeite axe distribution after Petrequin et al. 2011 Fig.1. with new Hungarian sites known till March 2014 added in the little red rectangle. (see in details Bendő et al., this volume)

5. ábra: A jadeit balták elterjedése Petrequin et al. 2011 Fig.1. alapján, kiegészítve a 2014. márciusáig megismert új magyarországi darabokkal (ld. Bendő et al., ebben a kötetben)

Using this method, the sizes and shapes of the artefacts were advantageous in their digitizing, however, the blurred contours, the homogeneity and the lack of contrasts of their surfaces were disadvantages. In this case, the surface flaws of the 3D models were more difficult to spot, but they were easier to correct. On the other hand, the 3D models were suitable for measurement only with software correction. Generally speaking, this process is cheap, fast, it reqires fewer tools and less workforce, the tools are used daily in most scientific institutes and museums. However, picture element matching is a less proven method, however, the prospects of its applications are improving.

Taking everything into consideration, the process based on picture element matching is suitable for the non-destructive analysis and the visualisation of these artefacts.

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