LIETUVOS ARCHEOLOGIJA. 2024. T. 50, p. 69–103. ISSN 0207-8694
https://doi.org/10.33918/25386514-050005

NEW INSIGHTS INTO THE PRODUCTION AND EXCHANGE OF LATE BRONZE AGE KAM AXES: APPLICATION OF 3D VIEW TECHNOLOGIES

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The production and distribution of the so-called KAM axes has been the subject of much discussion in Bronze Age research. The origins and technological sources of KAM axe production remain still unknown. KAM axes are characterized by long necks, a decoration matrix consisting of a number of raised horizontal lines that are looped and crosscut by one or more vertical lines. However, there are several subtypes of KAM axes, the existence of which contradicts the hypothesis about uniform axe distribution across the vast region between Central Sweden and the Volga-Kama region. Indeed, the rich assemblage of clay casting molds found in the Late Bronze Age fortified settlements in the Eastern Baltic region reveals that KAM axes were available in different sizes and shapes even if they appear to be uniform at the first glance. This paper presents the results of reconstructing clay casting molds through 3D laser scanning and postprocessing to (1) release a much more accurate view of molds and decoration patterns of the axes; (2) provide a comparison of axe parameters from the Eastern Baltic, Scandinavia, and the Volga-Kama regions, (3) further inquire about local and foreign productions; and (4) ascertain the significance of the decoration matrix as a communication code in the Late Bronze Age exchange and trade.

Key words: KAM axes, Bronze Age technologies, 3D laser scaning, archetypes, communication codes.

Vadinamųjų KAM kirvių gamyba ir paplitimas yra dažnas bronzos amžiaus tyrimų objektas. Iki šiol vis dar neaišku, kur atsirado KAM kirviai. Šiems kirviams būdingos ilgos įmovos ir puošybos matrica, kurią sudaro keli voleliai, kertami viena ar keliomis vertikaliomis linijomis. Tačiau yra keli KAM kirvių potipiai, prieštaraujantys hipotezei apie vienodą kirvių paplitimą didžiuliame regione tarp Vidurio Švedijos ir Volgos-Kamos regiono. Iš tiesų, gausus molio liejimo formų rinkinys, rastas vėlyvojo bronzos amžiaus įtvirtintose gyvenvietėse Rytų Baltijos regione, atskleidžia, kad KAM kirviai buvo įvairių dydžių ir formų, net jei iš pirmo žvilgsnio jie atrodo visiškai vienodi. Šiame straipsnyje pirmą kartą Baltijos šalių bronzos amžiaus tyrimuose pristatomos molio liejimo formų 3 D rekonstrukcijos ir jų analizė, siekiant (1) atskleisti daug tikslesnį kirvių formų ir puošybos elementų vaizdą; (2) palyginti kirvių parametrus iš Rytų Baltijos, Skandinavijos ir Volgos-Kamos regionų; (3) išsamiau išsiaiškinti vietinės ir nevietinės gamybos ypatumus; (4) atskleisti puošybos matricos kaip komunikacijos kodo reikšmę vėlyvojo bronzos amžiaus mainuose ir prekyboje.

Reikšminiai žodžiai: KAM kirviai, bronzos amžiaus technologijos, 3D lazerinis skenavimas, archetipai, komunikacijos kodai.

INTRODUCTION

Bronze Age researchers remain fixated on knowing more about the so-called KAM axes. In particular, they wish to shed light on how it was possible for the same typological code of axes, that emanated from the same time period,[1] to gain popularity in different regions that are far from each other. It is yet to be determined whether these KAM axes originated from the Volga-Kama region or Scandinavia. Indeed, it is difficult to find an applicable prototype of KAM axe from which other variants may derive based on Sergej Kuzminych taxonomies of KAM axes along different regional lines (Kuzminych 1996, Fig. 1).

The similarities between KAM axes is the natural product of transregional communication between Eastern and Northern Europe during the Bronze Age,[2] and was clearly observed in the analysis of artefacts recovered from North-western Russia, the Eastern Baltic Region and Fennoscandia (Juschkova 2011). However, the fact that the casting molds for KAM production are mostly found in the Eastern Baltic Region as opposed to their core areas of distribution in the Mälarden lake in Central Sweden and the Volga-Kama region of Russia, raises the question about where the said axes were produced. The numerous fragments of clay casting molds for KAM axes were found at the hilltop settlements in the Eastern Baltic in contrast to the few molds in the North and in the Volga-Kama region.

Recently, researchers revisited the question about the provenance of KAM axes, suggesting that Nordic KAM axes are not uniform but instead vary by region and include distinct subtypes (Eriksson 2009, 250; Melheim 2015). First, the original KAM style emerged and spread to other landscapes. Accordingly, copies were made and similar type axes were innovated, such as the Norwegian type (Melheim 2015). Melheim's approach is unique in that she was the first to talk about axe replicas, style dynamics and innovations that influenced the emergence of similar but distinctive types in peripheral regions (ibid.).

It bears mentioning that the foregoing discussion about KAM axes preceded the analysis of archaeological material from the Eastern Baltic region which focused on a large number of clay casting molds pertaining to these axes. Novel studies of technical pottery complexified the question regarding the origins of KAM axes (Čivilytė 2014; Podėnas *et al.* 2016; Podėnas, Čivilytė 2019). Specifically, casting molds with representative negatives were mostly used for KAM axes, which suggests the presence of metallurgical influence from Scandinavia (Podėnas, Čivilytė 2019). The spread of *know-how* and traveling craftsmen from the North imply that KAM production in the Eastern Baltic was inspired by Nordic entities as opposed to their Russian counterparts (Čivilytė, Duberow *in prep.*).

Nevertheless, the exact origins of KAM axes remain unknown and archaeologists may only speculate in that regard. However, one of the crucial aspects that needs more careful attention is the measurement of parameters of KAM axes to determine the degree of precision required to duplicate so many objects. The parameters and their proportions play a very important role in ascertaining

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[1] KAM axes are difficult to date. They occur in the graves of Volga-Kama regions in 8th–6th century BC. The Nordic KAM axes are dated from 1300–1100 to 500 BC. More precisely, the Swedish ones are usually dated to period IV and VI but without secure find contexts (Montelius 1917, 1054-5, 1169-1179; Baudou 1953, 242–243). The casting molds of KAM axes in Eastern Baltic region are found in settlements that date back to 10th-9th century BC (Podėnas 2020). The wooden shaft from the KAM axe from Astangu is dated 516–374 BC (2σ) (Paavel et al 2019, 5).

[2] I. e. Textile-impressed Ware, Striated Ware, Dnepr-Daugava-Ware cultural circles (Kuzminych 1996). A. Tallgren first made this observation in 1937. However, E. Baudou noted as early as 1953 that the Swedish types did not correspond to the Russian ones (Baudou 1953, 248).

whether it was a mass and standardized production or the spread of an idea of form and decoration with local variations.

Although the evolution of metallurgical technology in the Eastern Baltic region is much discussed, the parameters of KAM axes remain largely unknown. Aleksiejus Luchtanas observed that KAM axes produced in Lithuanian hillforts were not Nordic replicas. Instead, locals created their own KAM axes, which are similar but differ from Swedish ones (Luchtanas 1982, 11). Luchtanas noted the approximate dimensions of one axe, which he obtained from the best preserved double clay mold from Narkūnai (Lithuania) (Table 2, 7). Accordingly, the axe was 85–95 mm long and the neck 25–31 mm long (Luchtanas 1982, 9). However, it is difficult to assess the parameters of other axes given their fragmentary state. Yet, it is important to analyse these casting molds to establish clarity on the genesis and local characteristics of these axe forms.

In this article, we will use 3D scanning technology to get an accurate picture of the casting molds from the Lithuanian and Latvian Late Bronze Age hillforts of Narkūnai (Utena district), Mineikiškės (Zarasai district), Ķivutkalns (Salaspils district)[3]. Next, we will make virtual "copies" from the negatives of the 3D models by flipping normal of the mesh. In doing so, we will measure their proportions as accurately as possible, and compare them with their counterparts in Sweden, Russia and single finds from the Eastern Baltic region. We will also focus on the peculiarities of axe ornamentation in order to identify the technological and conceptual differences between the different axe groups (Table 2).

TECHNOLOGICAL PROPERTIES OF CLAY MOLDS OF KAM AXES: A BRIEF REVIEW

The typological and analytical characterization of casting molds at "Didysis" Narkūnai hillfort was recently published by Agnė Čivilytė. In her monograph, she first classified these molds with special attention to their technological patterns (Čivilytė 2014). Generally, in the Eastern Baltic region mostly double- sided casting molds for socketed axes were found and identified for a KAM type.

Out of 110 fragments of casting molds for axes, roughly 48, which amounts to 43.64% of all molds, carried distinguishable negatives. Most of the aforesaid fragments consisted of three horizontal grooves or featured other distinct decorations that are typically found on KAM axes (Podėnas, Čivilytė 2019).

All casting molds from Narkūnai are made from local clay deposits in the vicinity of the site.

In five cases, the molds were found in a double-layered condition. One of these molds has a striated lower layer, while the other has clearly visible rope or strap marks on the upper layer, which indicates that both sides of the mold have been covered with an additional clay layer and bound together. One of the molds features a dash on the outside, which is likely the mark of the master to distinguish different sides from one another (Čivilytė 2014, Tab. XVI, 19).

Several clay casting molds and crucibles from Narkūnai were carried out by instrumental analysis using XRF and SEM/EDX (Podėnas et al, 2016). The results provide significant information about the materials used for manufacturing the molds and metal residues therein. XRF measurements of the inside of clay moulds showed that Si and Al are the dominant elements. Small amounts of potassium (K), calcium

[3] The authors express their gratitude to the National Museum of Lithuania and the Latvian Museum of History for enabling us to analyse the casting forms.

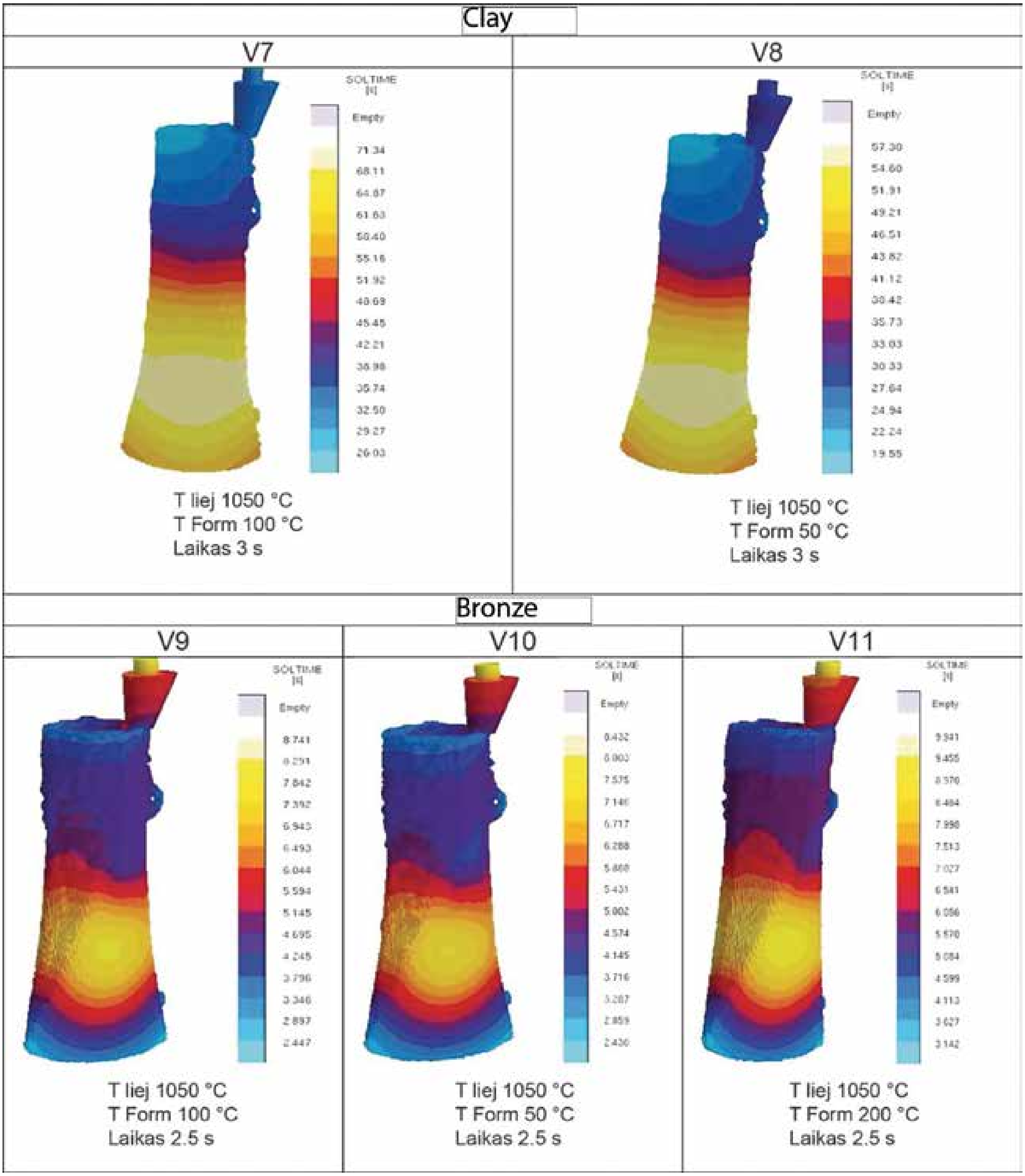


Fig. 1. The casting process of the KAM axe differs between clay and bronze molds. In the clay mold, the metal fills the form relatively quickly but begins to solidify in the neck area as the mold is filled. In contrast, the metal in the bronze mold solidifies much faster. *Simulation picture by M. Wirth.*

1 pav. KAM kirvio liejimo procesas molinėje ir bronzinėje formoje. Pirmuoju atveju metalas užpildo formą pakankamai greitai ir pradeda stingti ties įmova, lydiniui jau užpildžius formą. Bronzinėje formoje metalas stingsta labai greitai, dar neužpilžius formos. *M. Wirth simuliacijos pieš.*

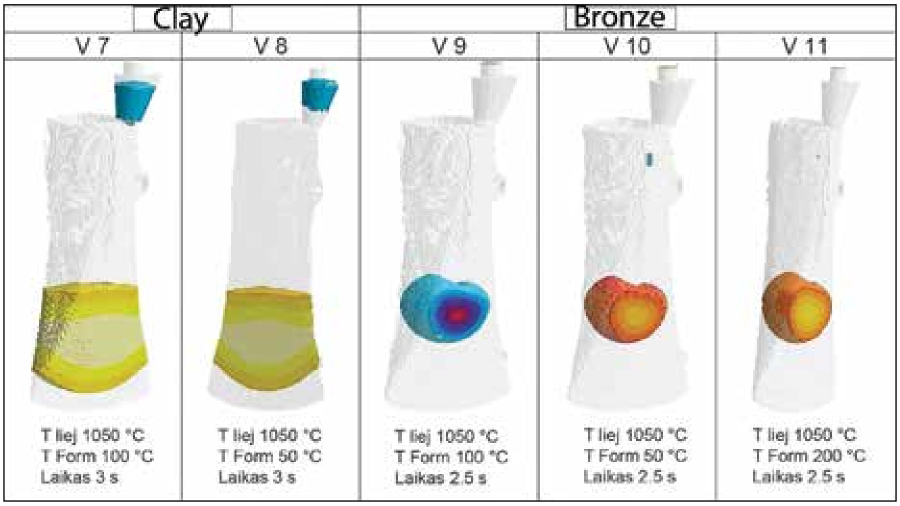


Fig. 2. The building of the so-called "hot spots" in the clay and bronze molds. *Simulation picture by M. Wirth.*
2 pav. "Poringųjų zonų" susidarymas molinėse ir bronzinėse liejimo formose. *M. Wirth simuliacijos pieš.*

(Ca), titanium (Ti), magnesium (Mg) and iron (Fe) were also found in the clay composition. copper (Cu) and lead (Pb) were detected at rates of 0.02-0.1 % and 0.14 % respectively. When the molds were microscopically examined, small concentrations of brown grains were found on an uneven surface. Copper (Cu) and zinc (Zn) metal ions were found after the said brown grains were microchemically and qualitatively tested.

EDX spot analysis of crucible fragment samples shows an extremely uneven distribution of chemical elements in the samples. Namely copper (1–10.7%), tin (3.9–53.6%), and lead (0.9–8.5%) were detected, confirming the fact of metal smelting in these crucibles.

Instrumental analysis only detected definite metallic residues on the surfaces of the vitrified crucible fragments, while the remaining fragments of technical pottery did not contain more than 0.5 % of copper, tin, zinc or lead in the measuring points. The clay also absorbs some of the metal alloys during deformation and determines the colour of the specific point of deformation. The X-radiography revealed that traces of metal spilled into the interior of the crucible walls through the heat-expanded pores of the alloy (Podėnas et al. 2016).

One KAM axes AR 107:4 was analysed through numeric simulation to better understand the function of clay casting molds and the efficiency of the casting technology of KAM axes (Čivilytė 2014, 71–74). (Fig. 1). The melting temperature is 1040–1060 o C and the melting time is 2-3 seconds. The axe is covered with a deep green patina. Its dimensions are 10.5 cm in length together with a blade that is 4.2 cm wide, its socket is 6.9 cm, and it weighs 210g. The casting seams are partially visible.

Computer simulation and experiment with different casting molds made of clay, stone, and bronze revealed different results regarding the casting process of this axe. The metal fills the mold very quickly when casting this axe in a clay mold. (Fig. 1). It cools evenly and rather steadily (for about one minute) from the bottom and towards the top centre. An expanded pore zone forms in the middle of the axe, which is completely different from the metal form. The temperature of the alloy drops after it has filled the cavity by only 80 %, with the alloy cooling down in only 9–10 seconds.

Optimum mold and alloy temperatures are required for better results; in particular, to fill the areas of ornamentation. In this case, the bronze mold is not suitable because the casting process is much more complex. Casting in the bronze forms causes the formation of so-called "hot spots" which makes the axes breakable in the middle of the axes body (Fig. 2). Moreover, clay and stone molds have better isolation because they comprise minerals. All in all, casting in the clay molds was much more advantageous than in stone or especially in bronze mold.

APPLICATION OF 3D TECHNOLOGIES TO CLAY CASTING MOLDS

21 fragments of clay casting molds from the National Museum of Lithuania and the Latvian History Museum with informative patterns, such as adequate size and decoration, were selected for our analysis (Table 1–2). It was possible to identify the fragments as parts of the same axes in three cases (Table 2, Nr. 2–4). With exception of the Nr. 16, all axes belong to the KAM type.

For 3D digitization, 3D laser scanning method was selected because of the known issues and weaknesses of geometrical data acquisition techniques like single point measurement or photogrammetry (Marzouk 2020, 54). Accuracy of the volumetric measurement is a crucial part of the digitization because archaeological finds are relatively small artefacts with various micro geometry characteristics on the molds which should be preserved during digitization, e.g. loss of information in the digitalization process must be minimal[5] (geometrical point of view). As such, we can see the details of the objects more accurately, which is not possible to do via macroscopic observations.

Since the 1990s, 3D view technologies have been used to various types of measurements for cultural heritage objects (Acke at al. 2021; Acke 2024). These 3D technologies include various digitalization practices, methods, tools and methodologies. In this article, the term *virtual restoration*[4] will be used.

The goal of this experimental survey – digitally extract 3D archaeological artefacts (Bronze Age axes) from the actual molds which are analysed here. *Virtual restorations* in this article means the process of 3D digitization, 3D model creation, 3D model optimization, 3D model inversion, cleaning and 3D model alignment with rest of the same archaeological artefact 3D models which were processed accordingly in a same workflow (Table 1). To view the 3D forms, you first need to download and install MeshLab by clicking on https://www.meshlab.net/#downoad. Once the program is installed on your device, you can open the provided link where all the 3D models are saved. This will allow you to explore and interact with the 3D forms using MeshLab's powerful visualization and editing tools. https://drive.google.com/drive/folders/1byoO95sbswvDIHLh_kLxFt--akBjm9Qk?usp=sharing

PHYSICAL PARAMETERS OF KAM AXES

In the following, we will analyse the physical parameters of the KAM axes in order to understand their metric standards (length, proportions, weight ranges). We will first start with the bronze axes, kept in the National Historical Museum in Stockholm. They build a statistically significant group, which we have analysed physically. All axes are supposed to be found in Sweden.

In the second and third steps, we will proceed with the bronze axes found in Lithuania, Latvia and Estonia. Furthermore, we will work with the parameters derived from our 3 D scanning (Table 2). This is important due to the fact that there are only 9 bronze KAM axes found in the Eastern Baltic. As such, our measurements deliver additional information which could not be done before.

[4] "Virtual restorations are restorations that remain virtual and they can be considered a study of a previous state of the object, based on existing documentation" (Acke et al. 2021).

PROCESS STEP	ACTION	METHOD	TOOL	CHARACTERISTICS OF THE TOOL	RESULT
1.	3D digitization	3D laser scanning	FaroArm 3D scanner	Model 14000, Volumetric precision +-0.034 mm	3D point cloud of the part of the mold
2.	3D model creation	Triangulation of the point cloud	Software: Geomagic Wrap	Version 2021.2.2: 64 Bit Edition (2021.2.2.3022)	High detail mesh with no RGB values
3.	3D model optimization	Size and network of triangles optimization for size lowering	Software: Geomagic Wrap	Fixing non-manifold edges, self-intersections, highly creased edges, spikes, small tunnels, small holes.	Optimized triangle count (up to 5 million triangles) mesh with no structural errors and optimized surface vertex and faces network for the size.
4.	3D model inversion	Flipping normal versions of the faces of the mesh	Software: MeshLAb	Software: MeshLAb	Inverted mesh
5.	3D model cleaning	Deleting unnecessary parts of the mesh	Software: MeshLAb	Software: MeshLAb	3D model of the axe's part
6.	3D model alignment	Alignment of the separate axe's parts into single 3D model (if applicable)	Software: Geomagic Wrap	Version 2021.2.2: 64 Bit Edition (2021.2.2.3022)	3D model of the axe
7.	2D photography	Digital photography	Nikon D5200,	Nikon D5200 24.1 MP CMOS, + Digital SLR with 18-105mm f/3.5-5.6 AF-S DX VR ED NIKKOR Zoom Lens.	2D photo of the object (300 DPI, 20-24 MP).

Table 1. Digitization process. *Table by T. Žižiūnas*
1 lent. Skaitmenizavimo procesas. *T. Žižiūno lent.*

SWEDISCH KAM AXES

The distribution of length values of the Swedish axes suggests that they can be grouped into distinct clusters based on their lengths (Fig. 3).

The first group consists of axes with lengths ranging from 89 mm to 100 mm, including seven axes in this range. The second group contains axes with a length from 104 mm to 110 mm, showing a clear repetition of three axes having a length of 105 mm and two axes of 107 mm and 110 mm lenght. The third group encompasses axes with lengths of 111 mm to 120 mm with three repetitions of 112 mm and two repetitions of 113 mm. The fourth group consist of axes with the length range from 121 mm to 129 mm with the repetitions of three axes with the length of 122 mm. The fifth group contains axes with lengths ranging from 132 mm to 140 mm.

The repetitions in size likely reflect a standardized size range for these axes. While most axes fall into well-defined ranges, there are a few outliers, especially in the higher length range (e.g., 140 mm), which might represent unique characteristics or deviations from the norm.

As a second step, we analysed the weight ranges of axes (Fig. 4). Some weights of the axes appear multiple times, and the axes are divided into five groups. The first group consists of axes from 147g to 206 g, the second group has axes ranging from 216 g (two examples) to 230 g. The third group includes axes with the weight of 246 g (two examples) to 254 g,

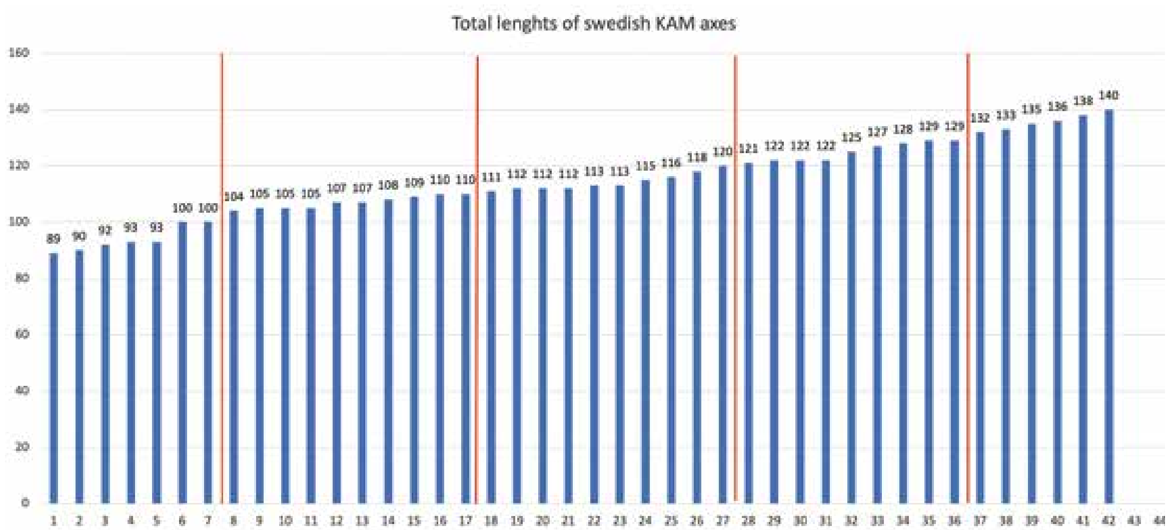


Fig. 3. Parameters of Swedish KAM axes. *Diagram by A. Čivilytė.*
3 pav. Švedijos KAM kirvių parametrai. *A. Čivilytės brėž.*

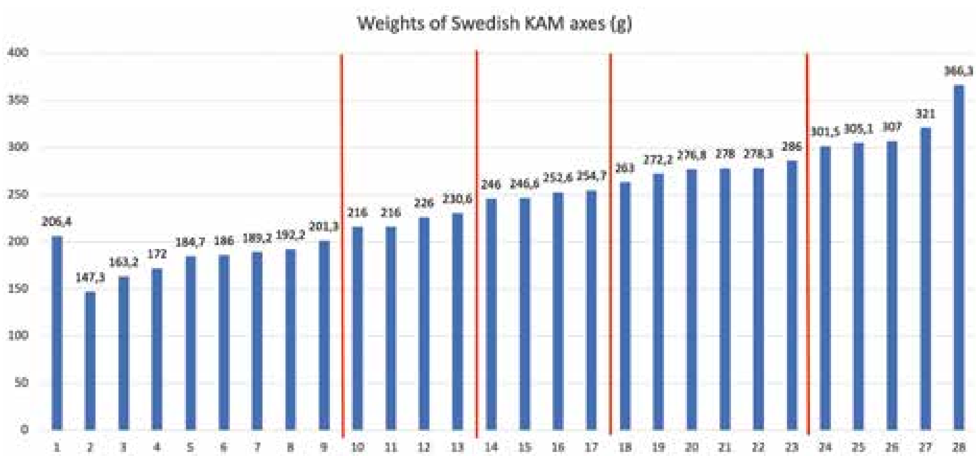


Fig. 4. Weight ranges of Swedish KAM axes. *Diagramm by A. Čivilytė.*
4 pav. Švedijos KAM kirvių svoris. *A. Čivilytės brėž.*

the fourth group builds a row of axes from 301 g to 321g and the heaviest axe as an outliner weights 366 g. This breakdown helps to understand the distribution of axe weights and identifies the main weight ranges.

Next, we compared the total length of axes (mm) and their weights (g) (Fig. 5). There is a positive correlation between the lengths and weights: as the length of axes increases, their weight tends to increase as well. The consistent increase in both length and weight across most of the axes suggests that larger axes are proportionally heavier. However, there are instances where axes of similar lengths have significantly different weights (e.g., axes 5 and 9, where the lengths are similar, but the weights differ substantially). Some axes stand out due to either their unusually high weights relative to their

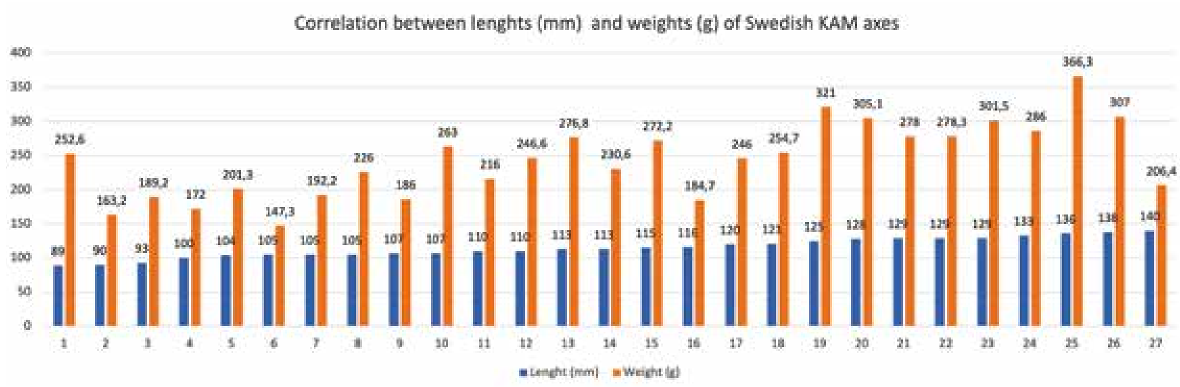


Fig. 5. Correlation between length and weight of Swedish KAM axes. *Diagramm by A. Čivilytė.*
5 pav. Švedijos KAM kirvių ilgio ir svorio santykiai. *A. Čivilytės brėž.*

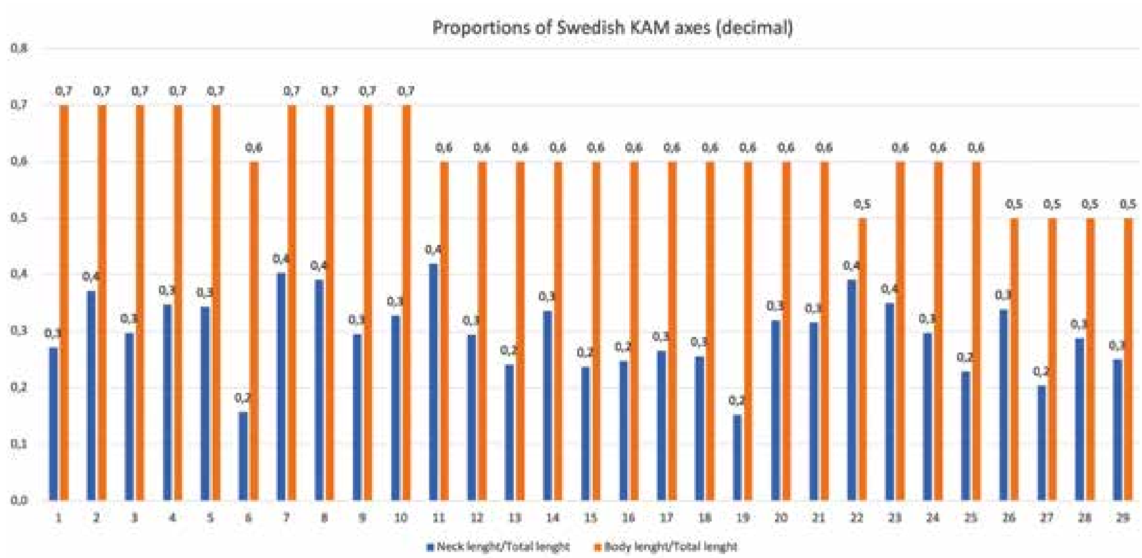


Fig. 6. Proportions of Swedish KAM axes (decimal values). *Diagram by A. Čivilytė.*
6 pav. Švedijos KAM kirvių proporcijos (dešmtainė sistema). *A. Čivilytės brėž.*

lengths (e.g., axe 1) or unusual ratios between the two measurements.

Finally, we aim to analyse the proportions of KAM axes by determining a) the relationship between neck and total length and b) between the body and total length (Fig. 6). The neck is measured from the top of the socket to the first horizontal line, and the body is measured from the last horizontal last to the cutting edge (Tab. 2). We calculate the proportions as decimal values:

Proportion of Neck (Hals) Length to Total Length = Neck Length / Total Length;

Proportion of Body Length to Total Length = Body Length / Total Length.

The space between these two sections of the axe's body is filled with mostly four (21 example) or five (10 example) horizontal lines and measures from 7 to 11 mm. The loop is within this area of horizontal lines. The Swedish axes mostly have four horizontal lines, although five lines are also common.

Figure 6 provides insights into the distribution of the axes' proportions, allowing for an understanding of the frequency and distribution of axes with different neck and body proportions.

The range of the neck proportion is between 0,2 and 0,4. Most values of neck proportions are centred around 0.3 and 0.4, with a few at 0.2. This indicates that the majority of axes have relatively longer neck lengths compared to their total lengths. The range of the body proportion is mostly around 0.6 to 0.7, showing that the body length makes up the majority of the total length.

For most axes, the combined proportions of the neck and body length add up to approximately 1. This consistency suggests clear, defined proportions between the neck and body across the axes.

Some axes (e.g., 22, 23, and 29) show a proportion of 0.5 for body length, indicating that the neck and body lengths are more evenly distributed for these items compared to others.

There seems to be a positive correlation between the neck and body proportions, although it's not very strong. As the neck proportion increases, the body proportion tends to increase slightly. These observations highlight the standard proportions in Swedish KAM axes, with the body length being the dominant portion of the total length. The slight variations in the neck-to-body ratios may reflect functional or stylistic differences between individual axes.

To summarize our observations on Swedish KAM axes, we can review their parameters. First, the repetitions in the length system can be understood as manufacturing standards or practices. The craftsmen might produce axes in specific lengths that are commonly used or requested by customers. Among the analysed axes, there are two axes which are identical in their parameters and decoration patterns (Fig. 12), indicating their production in one casting mold.

EASTERN BALTIC KAM AXES

None of the nine KAM bronze axes from Eastern Baltic region (Fig. 13). are identical, as each axe has different parameters. One axe was remade into a chisel (Fig. 13, 3).

The distribution of length values (Fig. 7) indicates the small size of the axes, which generally differ from the Swedish examples, except from the first group with 89-93 mm and second group with 105 mm.

In contrast to the Swedish axes, the Eastern Baltic finds have only three horizontal lines between neck and body with one exception of the axe from Astangu (Fig. 13, 6). The space between these two sections measures between 7 and 12 mm.

The triangle decoration on two of the KAM axes (Fig. 13, 2, 7) in the Eastern Baltic also feature on one of the Swedish axes too (Fig. 18, 16).

If we analyse the *neck/total length and body/total length* proportions of the Eastern Baltic axes (Fig. 8), as we did with the Swedish ones, there appears to be a general trend where an increase in the proportion of the neck correlates with a moderate increase in the proportion of length, particularly at certain data points. For instance, the highest neck proportion (0.3) occurs alongside a relatively high length proportion (0.7), suggesting that larger neck measurements may be associated with greater length proportions. Furthermore, the body length seems to be in general relatively high in case of Eastern Baltic axes. As such, similar to the Swedish axes, the Eastern Baltic ones show the correlation between the neck and body proportions, although in a slightly stronger way.

Swedish KAM axes exhibit greater variability and higher proportions in neck length (up to 0.5) compared to the Eastern Baltic axes, which are limited to 0.3. This suggests a structural difference in design, with Swedish axes favoring longer necks.

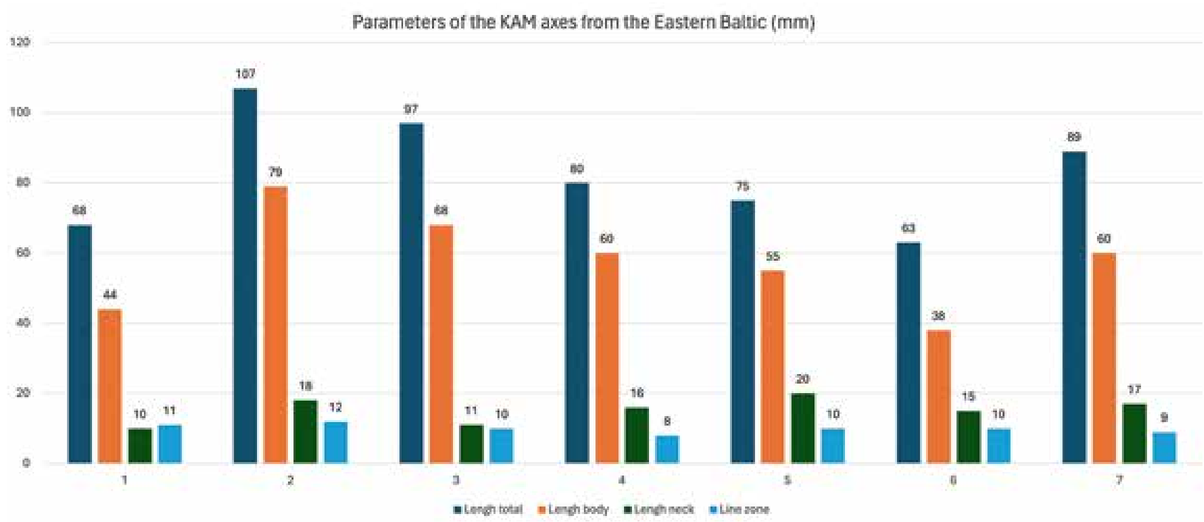


Fig. 7. Parameters of the KAM axes from the Eastern Baltic (mm). *Drawing by A. Čivilytė.*
7 pav. Rytų Baltijos regiono KAM kirvių parametrai (mm). *A. Čivilytės brėž.*

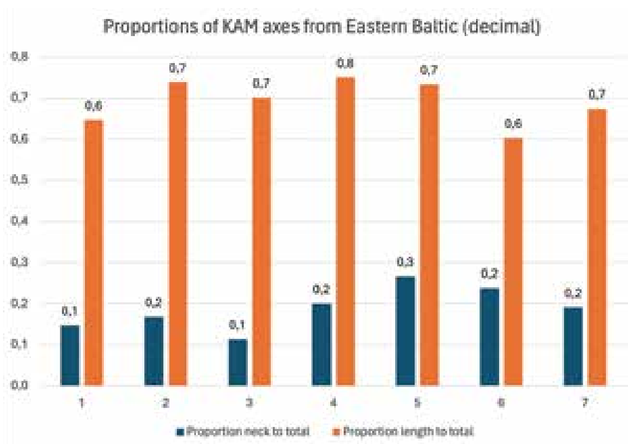


Fig. 8. Proportions of KAM axes from Eastern Baltic (decimal values). *Diagram by A. Čivilytė.*
8 pav. KAM kirvių iš Rytų Baltijos regiono proporcijos (dešimtainė sistema). *A. Čivilytės brėž.*

KAM AXES FROM VOLGA – KAMA REGION

We analysed 29 KAM axes from the cemeteries of Kozmodemjansk, Starsheje Achmylovo, Akozino, Ubejevo, Novo Mordovo, Mladsheje Volosovo, Ostashkov raj. and Starica raj. We did not have the opportunity to work with the original material at the museums in Russia, which is why we fixed the measurements of the axes according to the photos taken by our colleagues[5] many years ago and according to the publications.

S. Kuzminych divided KAM axes into 26 variants with regard to their shape (Кузъминых 1983, 80–90, Fig. 53). His typological tree clearly shows that it is

[5] We would like to extend our sincere thanks to Sergey Kuzminych for providing us with the photographs and additional information about KAM axes from the Volga-Kama region.

difficult to believe there was any kind of standardized production of axes. He notes that the axes from the cemetery of Akozino are significantly smaller than their counterparts from Starshyj Achmylovo. Their bodies measure from 70 to 90 mm. They all have three horizontal lines and short necks (Fig. 14, 10; 15–13).

If we look for the links to the Nordic and Eastern Baltic countries, we have a group of axes (types KAM 4 and KAM 22) which are very similar (Fig. 13, 4; 14, 6; 16, 29). Most of these axes are found in the cemetery of Starshyj Achmylovo (22 ex.). Interestingly, casting molds belong to the same type of the axes (Кузъминых 1983, 82, Fig. 54).

DIMENSIONAL ANALYSIS OF THE DIGITAL RECONSTRUCTION OF THE AXES FROM LITHUANIA AND LATVIA

One of the aims of this article was to create virtual reconstructions of the axes from 3D laser scanned molds made by inverting normal mesh triangles. In this way, we could create the dimensional characteristics of the best preserved fragments of casting molds and measure the same physical parameters of the axes as we did with the original metal finds (Table 2). The best preserved double-sided mold (Table 2, 7) enabled us to create a geometric model of the almost whole axe and allowed us to identify its original shape and dimensions. This axe was approximately 58 mm long – an extraordinarily small artefact. Thus, our results contradicts the previous assumptions of the size of this axe, suggested by A. Luchtanas.

We see a very similar situation is in the case of the axe No. 4. Based on its neck, we can assume the total length of approximately 57–60 mm. The axes No. 2 represents an exception, because the loop is missing. Furthermore, this axe is unusually long and measures aproximately 144 mm.

This case is intriguing, because measurements were taken in a new methodological way. Firstly, all three parts of the mold were scanned by 3D laser scanner (resolution is +-0.034 mm, see table 1). Secondly, two base grouping parts were virtually connected. Lastly, the third part was manipulated in a virtual orthographic projection, oriented and positioned at a distance where the shape lines of the known geometry could be visually extended in 3D to match the projection angle. Later, the axe form was extracted from this combined part (a joint of three archaeological pieces) by flipping the mesh normals and removing unnecessary sections. Finally, measurements were taken in the 3D view. These measurements were different than previous known calculations done by other methods (Luchtanas 1982). On the other hand, such proportions, long length of the axe is known by actual fully preserved archeological find in Sweden (Fig. 17, 1–2; 18, 13; 20, 32).

The 3 D laser scanned results show the parameters of the axes which were produced. In general, all axes have long necks and all of the axes have three horizontal lines. The axes from Ķivutkalns (Table 2, 13–14) show different patterns of the neck decoration with the vertical lines.

To summarize, the KAM axes found in the Eastern Baltic region were much smaller compared to those found in Sweden. This can be seen in two ways: first, by examining the actual bronze axes that have been uncovered, and second, by looking at the measurements of casting molds used for their production. In both cases, the Baltic axes were noticeably smaller. On the other hand, Swedish axes from the same period were generally larger in size.

RESULTS

The application of 3D view technologies offers huge potential for studying the surfaces and decorations of archaeological artefacts. Furthermore, 3D modeling of fragmented archaeological artefacts can serve as an effective tool for detailed typological comparisons and provenance studies, especially when macroscopic observations fall short. (Wilczek et al. 2015; Cara et al. 2021).

In our article, we first examined the clay casting molds in order to detect their morphological patterns. Doing so, we aim to understand their functionality, manufacturing processes and cultural significance. First, we were expecting the symmetry and uniformity of the forms, which would indicate precision in the design of axes and possibly the use of templates. However, 3D reconstruction clearly show the variations and individuality of casting molds. This may reflect experimentation or adaptation to specific requirements. For craftsmen, who worked at the hillforts, the ornamental patterns played a significant role. They served not for functionality but for aesthetic or symbolic purposes. Details which we can see on 3 D pictures, provide us cultural and artistic insights of the Late Bronze Age craftsmen in the Eastern Baltic region.

Computer simulations show that the most efficient axes are cast in clay molds (Fig. 1–2). It is therefore not surprising that bronze or stone molds are so rare among the archaeological findings in Sweden and surrounding Scandinavian regions. Therefore, we need to establish an understanding regarding the absence of evidence of clay molds in the regions with the highest concentration of bronze KAM axes. Such absence may be partially attributable to preservation conditions, but it is unlikely that clay molds had simply disappeared from the surface. The Eastern Baltic assemblage of clay casting molds contradicts this idea. Rather, it can be assumed that the axes were not produced in places where they were mostly used.

This brings us back to the fact that there is a rich collection of moulds in the Eastern Baltic region. The molds of KAM axes have been found in ten fortified settlements, and the axes themselves have been found in nine sites, one of which is a fortified settlement (Kļanģukalns) (Podėnas, Čivilytė 2019, Appendix 1). Recent works has suggested that craftsmen from Scandinavia used to come to the Eastern Baltic settlements and make KAM axes at these sites (ibid., Čivilytė, Duberow *in prep.*). However, our research clearly shows that these axes were considerably smaller and were not Scandinavian equivalents. Only the proportionality of the axes in relation to the neck and body has been maintained. Decorative elements are also repeated, which enable us to attribute this axe to the KAM type. Interestingly, the casting molds of KAM axes in Scandinavia art found in the peripheral regions, as is the case in Norway where three soapstone molds for the so-called Norwegian axe type (Melheim 2015, 195). These and the Eastern Baltic findings support the hypothesis that "hybrid" or "native" styles were produced in societies which were not directly connected to the main distributors of KAM axes.

Another important note is the chronology of the axes produced here. The molds are found in settlements that date back to 10th–9th century BC (Podėnas 2020). The wooden shaft from the axe from Astangu is dated BC 516–374 (2σ) (Paavel et al 2019, 5). We are therefore in a favourable situation, because we can attribute this axe to a specific archaeological period which indicates the use of KAM axes from Montelius P V till the Early Iron Age in the Eastern Baltic region. Except from the axes of Astangu, the chronology of KAM axes from the Eastern Baltic coincides with Scandinavian and Russian axes[6]. The only find kept in Sweden, which includes the KAM axe, is also typologically dated to Period VI (Fig. 9).

To culturally contextualize our results, we must consider the question if the Swedish axes could have

[6] 8th–6th centuries BC. There are also one ^{14}C-date of a wooden shaft belonging to a KAM axe from Up, Västeråker Parish. The date is calibrated to Period VI to early pre-Roman Iron Age (Hjärthner-Holdar 1998, 38).

Fig. 9. Period VI hoard found at Sigridsholm in Lunda (Up) 1986. Bronze Age lake location. *After Rundkvist 2015, Fig. 48*.
9 pav. VI periodo lobis, rastas Sigridsholme (Lunda) 1986 m. bronzos amžiaus ežero vietoje. *Pagal Rudkvist 2015, 48 pav.*

been produced via serial production. The fact that extremely similar (but not identical) KAM axes were distributed across two different regions, in the North and the East (several thousand kilometers apart), suggests the possibility that they may have been mass-produced. However, as indicated before, KAM axes were generally produced in clay casting molds, via *cire perdue*. This makes the serial production impossible, unless the craftsmen were using templates made of wood, clay or metal. The latter could be sufficiently used as bronze prototype for making casting molds as negatives. Hence, further investigation should be done to prove this hypothesis.

Another suggestion is that the worn-out axes were copied to molds and directly recycled into new axes (Melheim 2015, 200). However, the clay casting molds as templates in the Eastern Baltic do not support this assumption because judging from 3D digitization significantly smaller axes were produced at the hillforts. The three horizontal lines contradicts the idea of bronze templates too, because the Nordic axes usually have four lines.

First of all, it is noteworthy that even if some KAM axes from Volga-Kama region have astonishing similarity to Swedish ones (Fig. 15, 4; 16, 22) a significant group of these axes differ from the latter through their ornamental patterns. Obviously there was an intentional "mark" of local tradition not to follow the "copy-paste" principle, but to create independent style of decoration. This is especially visible in the horizontal line, where in contrast to the Nordic or Eastern Baltic axes, the line develops into a sharp triangle (Kuzminych type KAM 2/22) (Fig. 15,

Fig. 10. Collection of axes in the Swedish history museum. *Foto by A. Čivilytė.*
10 pav. Kirvių kolekcija Švedijos istorijos muziejuje. *A. Čivilytės nuotr.*

12; 16, 23, 25, 27). There are also two ellipsoid holes next to the vertical line, which is not common in the Swedish or Eastern Baltic axes (Kuzminych type KAM 6) (Fig. 14, 8; 15 11).

However, some of Russian KAM axes again resemble to Eastern Baltic counterparts: they are small and have similar proportions as well as the decoration patterns. Special attention should be drawn to axes with the triangular decoration on the necks. These ornaments appear on singular KAM axes in Sweden, Lithuania and Russia (Fig. 13, 2, 7; 18, 16). and are described as an Eastern type. We consider the triangles as a specific letter, which was readable for some people. Such an ornament cannot be a coincidence – on the contrary, it shows the connections between communities.

To understand the phenomenon of KAM axes, it is crucial to examine the relationship between their producers and the sources of metal. The central question concerns the origin of the copper used in these axes and whether distinct sources can be identified for the Northern and Eastern regions. Preliminary analyses of KAM axes from the Volga-Oka region suggest the use of copper from the local copper sources of the Ural Mountains (Кузъминых 1983, 90), while the Nordic examples (at least the Norwegian/Western Scandinavian) appear to be linked to European copper ores (Mehlheim 2015, 194).

A considerably huge amount of Russian KAM axes were metallurgically analysed and published (Кузъминых 1983; Кузъминых, Орловская 2017).

Fig. 11. Collection of axes in the Swedish history museum. *Foto by A. Čivilytė.*
11 pav. Kirvių kolekcija Švedijos istorijos muziejuje. *A. Čivilytės nuotr.*

Here we have the problem of the methodology, which is not comparable to the technique used today[7]. However, the measurements of the elements of the artefacts show the existence two main chemical groups. In the first groups, artefacts made of antimony-arsenic alloys are dominant. The second group contains finds made of pure copper without any intentional alloyed elements. Regarding the metallurgical groups, there is a clearly dominance of copper alloys with tin, where local Uralian copper sources were used (Кузъминых 1983, 10-11). Recent metallurgical analyses, including lead isotopes from Russian archaeological sites have provided significant results, which will contribute to a more comprehensive understanding of the origins of KAM axes (Čivilytė, Pernicka, *in prep*.).

Furthermore, the cultural context of KAM axes and their production sites must be taken into account. These artefacts belong to a specific typological group (i.e., KAM axes), associated with two major production centres, with unique versions produced in the regions surrounding the epicentres or miniature axes in the regions between these centres. The focus should shift from determining who first produced these axes to understanding why and how axes with similar proportions and decorative styles emerged independently in different parts of the landscape.

There is one more aspect which is of great relevance for the question of KAM axes, namely their find contexts. Almost all examined Swedish axes are

[7] Kuzminych worked according to the methodology of E. N. Chernych, which was efficiently used in archaeometry in the 90's (Chernych 1992). Here, the main components were measured and two groups – chemical and metallurgical were distinguished.

Fig. 12. Axes which were most probably produced in the same casting mold. *Foto by A. Čivilytė.*
12 pav. Kirviai, kurie tikriausiai buvo lieti toje pačioje formoje. *A. Čivilytės nuotr.*

either stray finds or they do not have any information about how and where they were found.

Axes are no longer deposited in graves after Period II/III in Scandinavia, unlike in Russia. There is one datable hoard in Sweden containing a VII:B1a-type axe, dated to Period VI (Fig. 9). Additionally, there is one example of a VII:B1a axe from a hill settlement at Darsgärde, Skederid Parish, Uppland. The other material from this settlement is dominated by pottery of eastern character, including Finnish or east-Baltic pottery from the late Bronze Age or early Pre-Roman Iron Age (Reisborg 1998, 84).

The Russian axes and the casting molds are all from the cemeteries, that means they all were part of the grave goods. The Eastern Baltic casting molds were all discovered in fortified settlements, whereas the bronze axes, except for one,[8] are all stray finds. These archaeological contexts clearly depict the

[8] The famous hoard from Vaškai (Konstantinovo) in Northern Lithuania is problematic, because the KAM axe seems to be a modern copy. As such, we do not intend to include this axe into our analysis.

Fig. 13. KAM axes from Eastern Baltic region. *Foto by A. Čivilytė (2–5); after Merkevičius 2011 (1); Latvijas senākā vesture, fig. 129 (7).*

13 pav. KAM kirviai iš rytinio Baltijos jūros regiono. *A. Čivilytės nuotr. (2-5); pagal Merkevičius 2011 (1); Latvijas senākā vesture, pav. 129 (7).*

1 – Kalbutiškės; 2 – location unknown; 3 – location unknown; 4 – Zveijsalas; 5 – Jekabspils; 6 – Astangu; 7 - Ludzas.

Fig. 14. KAM axes from Volga-Oka region.
14 pav. KAM kirviai iš Volgos-Kamos regiono. *S. Kuzminych nuotr.*
1-5 Ubejevo (without scale); 6- 9 Kosmodemjansk 10 Akozino. *Foto by S. Kuzminych*

Fig. 15. KAM axes form Volga-Oka region. *Foto by S. Kuzminych.*
15 pav. KAM kirviai iš Volgos-Kamos regiono. *S. Kuzminych nuotr.*
11-13 Akozino; 14-20 Starszeje Achmylovo.

Fig. 16. KAM axes form Volga-Oka region. *Foto by S. Kuzminych*.
16 pav. KAM kirviai iš Volgos-Kamos regiono. *S. Kuzminych nuotr*.
21-24 - Starszeje Achmylovo; 25 – Novo Mordovo; 26-27- Spasskj raj., 28 – Jung Volosovo; 29 – Starica raj., 30 – Ostaschkov raj.

Fig. 17. KAM axes from Swedish History Museum. *Foto by A. Čivilytė.*
17 pav. KAM kirviai iš Švedijos istorijos muziejaus. *A. Čivilytės nuot*r.
1 – SHM 13487- 419016 (Västergötland, Stommen); 2 – SHM 7578-6-418791 (Västergötland, Västerbitterna socken, Tålanna by); 3 – HST 3937- 3009464; 4 – HSM 18379- 1209562 (Uppland, Rasbo socken, Västerberga); 5 – HSM- 12282- 419189 (Gottland, Akebäck socken, Suderbys); 6 – HST 14613-3009493 (Södermanland, Husby-Rekarne socken, Årby); 7 – HST 11069 – 3009499 (Södermanland,Spelvik socken, Malmköpingstrakten); 8 – SHM 5677- 417166 (Västergötland, Habo socken, Hökesjön); 9 – HST 16401- 3009497 (Södermanland, Överjärna socken); 10 - HST 8640-3009500 (Trosa socken/Herrberga);

Fig. 18. KAM axes from Swedish History Museum. *Foto by A. Čivilytė.*
18 pav. KAM kirviai iš Švedijos istorijos muziejaus. *A. Čivilytės nuotr.*
11 – HST 2124 – 3009496 (Närke, Asker socken, Bysta, Sjön Sottern); 12 – SHM 6422_421954 (Gotland, Vall socken, Hardings); 13 – SHM 8520 - 1141991 (Södermanland, Botkyrka socken, Rikstena); 14 – SHM 8234 -2 – 422383 (Gotland); 15 - HST 9401-113847 (Närke, Västra Närke); 16 – SHM 13671-363115 (Södermanland, Husby-Rekarne socken, Eskilstunaån); 17 – SHM 15646-113860 (Västmanland, Svedvi socken, Fjällsta); 18 – SHM 25878 (F1064)-454339; 19 – HST 9170 – 3009495 (Uppland, Vänge socken); 20 – HST 1209563 – 10676 (Uppland);

Fig. 19. KAM axes from Swedish History Museum. *Foto by A. Čivilytė.*
19 pav. KAM kirviai iš Švedijos istorijos muziejaus. *A. Čivilytės nuotr.*
21 – SHM 8109 – 8 – 13856 (Uppland, Bro socken, Lejondal); 22 – SHM 14586 – 1209561 (Uppland, Rimbo socken, Rimbo stationssamhälle); 23 – SHM 17343 – 1444 – 415805; 24 – HST 7338-3009446; 25 - HST-14436-3036394 (Östergötland, Kuddby socken, Höckerstad); 26 – HST 2898-3009498; 27 – HST 16106-3009481 (Västmanland, Västerås socken, Stora Hejarna);

Fig. 20 KAM axes from Swedish History Museum. *Foto by A. Čivilytė.*
20 pav. KAM kirviai iš Švedijos istorijos muziejaus. *A. Čivilytės nuotr.*
29– SHM 5074 – 419534 (Gotland, Fardhem socken, Kvie); 30 – HST 7591 – 3009501; 31 – SHM 145316 – 416397 (Medelpad, Hässjö socken, Lögdö); 32 – HST 8762 – 3009465 (Skäne, Sädra Mellby socken, Svinaberg); 33 – HST 11069 – 3009492 (Södermanland/Spelvik socken/Malmköpingstrakten); 34– SHM 2417- 96817 (Södermanland, Vrena socken, Vrena);
35 – SHM 12036-1-97146 (Södermanland, Västerhaninge socken, Hållsätra); 36– HST 8353 – 2- 732814 (Uppland, Enköping socken, Enköping); 37– SHM 13991-4-1209559 (Uppland, Husby-Sjutolft socken, Ekolsund); 38 - SHM-17210-1209558 (Uppland, Håtuna socken, Killinge);

Fig. 21 KAM axes from Swedish History Museum. *Foto by A. Čivilytė.*
21 pav. KAM kirviai iš Švedijos istorijos muziejaus. *A. Čivilytės nuotr.*
39 – SHM 16362-4-1209560 (Uppland, Härkeberga socken, Malma); 40– HST 16388 - 113865 (Östergötland, Väversunda socken, Tyskeryd); 41 – HST 8234 – 15 – 3009494 (Södermanland, Eskilstuna socken, Eskilstunaån); 42– HST 9170-3036635 (Närke, Hammar socken); 43 – HST 9170_3036637 (Närke, Hammar socken).

ideological differences in the way, how past societies behaved with the artefacts in the last moment of their function. On the one hand, we see single depositions, while on the other hand, axes belong to the graves. These differences in the attitude towards the axes reflect independent development of a specific form of artefact.

To conclude our article, we therefore make two observations. First, we believe that production places do not necessarily mean that the artefacts would be used by local communities. On the contrary, the products could be transported away from production centres. Secondly, we conclude that the question of origin of KAM axes should not play a dominant role in the Bronze Age research anymore, because we think that all groups of axes were produced indigenously in separate regions. Of course, we have to assume that somewhere one of the styles was invented first and then spread across the borders, as Melheim suggests (Melheim 2015, 201), because people of the Late Bronze Age were exploring the world and there is no dispute about the cultural communications between different societies[9].

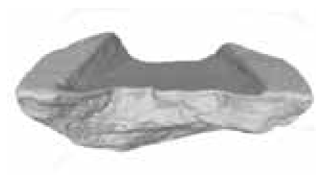
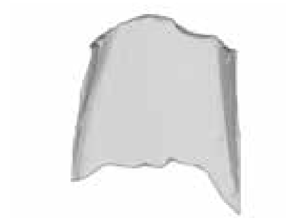
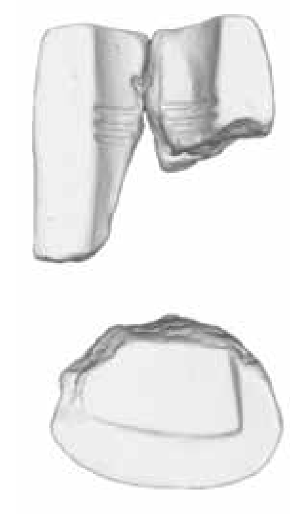
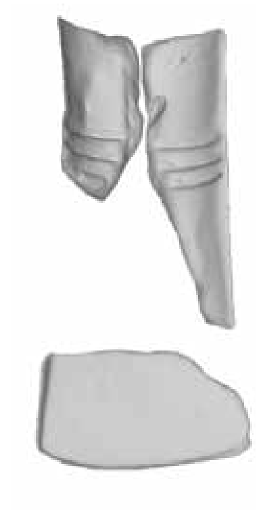
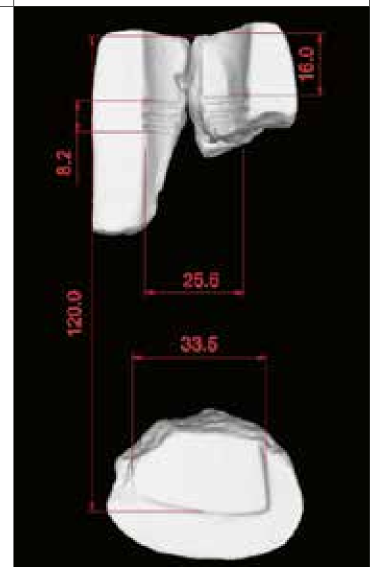
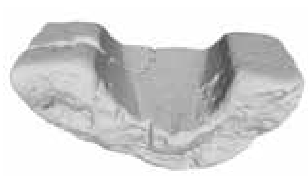
Furthermore, the concept of a single type of KAM axe cannot be applied, as there are various subtypes of KAM axes, making it impossible to use the distribution of all types to draw definitive conclusions.

The assemblage of the Eastern Baltic clay casting molds and their 3D digitization undoubtedly confirm the idea of local, individualized production of KAM axes with the main concept of proportions and decoration of certain axe type, although in a miniaturized version.

Moreover, the absence of casting molds in the regions of concentration of KAM axes should lead us to further investigations into their production

[9] Many scholars devoted their works to transcultural networks of Eastern Baltic and Scandinavia as well as Fennoscandian-Arctic-Russian connections in the Bronze Age (see Kuzminych 1996; Melheim 2015 with references).

Table 2.
2 lent.

No	ARTEFACT's METRIC	2D PHOTO	3D SCAN (OPTIMIZED)	FINAL RESULT	TARGET MEASURAMENTS (mm)
1.	Narkūnai, AR 594_489				
2.	Narkūnai, AR594-444				
3.	Narkūnai, AR 594-482				

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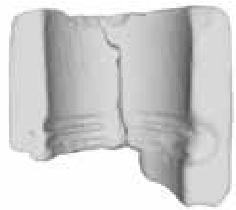
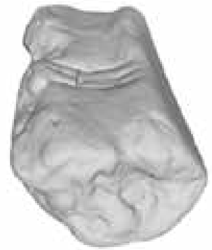
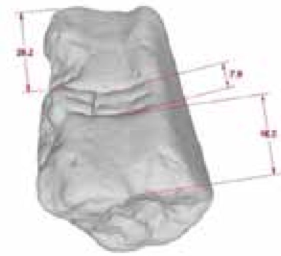
4.	Narkūnai, AR 594-483 and 594-499				
5.	Narkūnai, AR 594-486				
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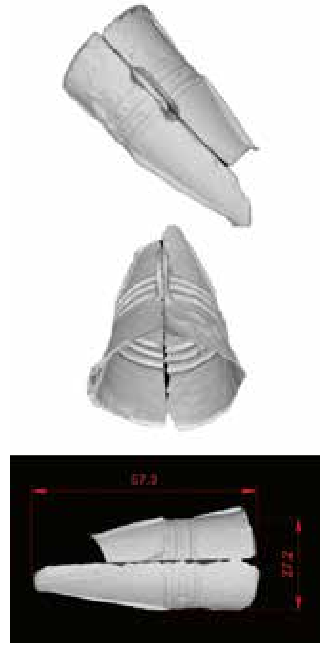
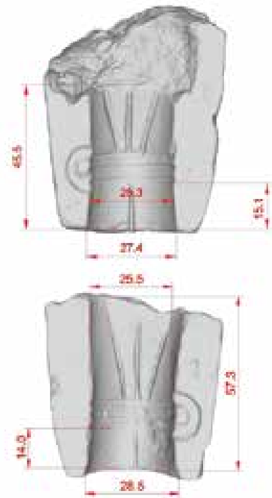
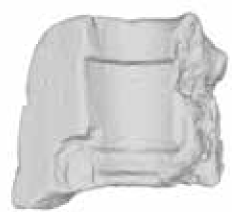
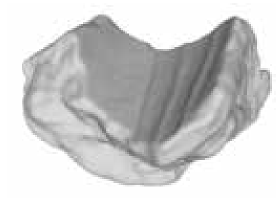
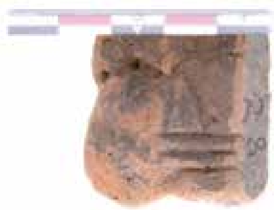
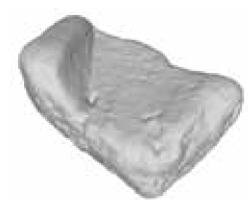
7.	Narkūnai, AR 594-495				
8.	Narkūnai, 594-498				
9.	Narkūnai, AR 594-555				

No	ARTEFACT's METRIC	2D PHOTO	3D SCAN (OPTIMIZED)	FINAL RESULT	TARGET MEASURAMENTS (mm)
10.	Mineikiškės, l. Nr. 212				
11.	Kivutkalns 28				
12.	Kivutkalns 120 10-15 VI 1966				
13.	Kivutkalns 203				

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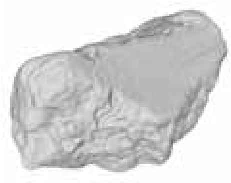
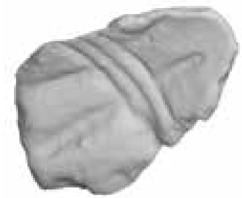
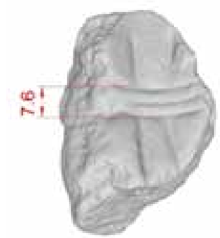
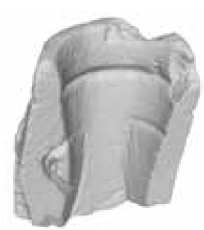
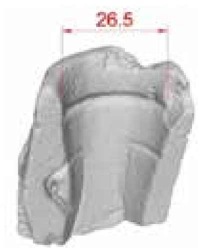
14.	Kivutkalns 397_1966				
15.	Kivutkalns 1244				
16.	Lichvardes dievukalns 29 1s80 340 17-B				

techniques and a detailed revision of old excavation materials as well as archaeological contexts. To continue, we have to consider how we can understand and interpret the striking similarities between artefact groups, which were used in regions far away from each other. Maybe it was the archetypical thinking, when objects were created independently in different societies? Furthermore, the question arise how a specific form of an artefact and its decoration can stimulate the cross regional communication networks in the past?

To sum up, we deal here with the active and discursive nature of material culture where typology is connected to specific production strategies. The "story of the long neck" of KAM axes according the Darwinian or Montelius perspective is already discussed with the conclusion that the long neck may not necessarily be a result of evolution. On the contrary, the long neck can be seen as an accident during the production process (Melheim 2015, 199-200). However, we think, that the extended or elongated neck of the axe was likely highly functional for heavier tasks such as felling trees, working with wood, and even combat.

Nevertheless, we have to keep in mind that archaeological objects are products of human activities and play an active role of the production of meaning and the creation of tradition, embodying specific codes and categories which can be continuously changed through human agencies (Sørensen 1997, 180). We therefore argue, that KAM axes represent an example *par excellence* of how archaeologists have to reconsider the typology of artefacts as human products and their final meaning as information tools for transhuman communications. The fact that the KAM axes were deposited in different contexts as grave goods together with casting molds in Russia and as single finds or elements of metal deposition in the hoards in the North illustrates the complexity of the axes "biography" and their final function as agents of cultural identity.

Interestingly, we face the unique situation in archaeological material where we observe the process of what is emphasized in the production of the objects, namely the informative value of an ornament and shape of an axe, which we usually describe as a type. The local versions and the production places with clay casting molds of these axes in the Eastern Baltic region reflects the importance of the shape of the object and its proportions. Furthermore, we can see the power of decorative elements for Bronze Age communities with some individual variations within the stable matrica. The motifs, which are recognizable (readable) by all, show that they were significant in a specific period of time and that they carried a message which we are not yet able to understand.

By studying the specifics of KAM axe production and the origins of the copper used, we aim to uncover technological differences between the East and the North. We believe that the significance of symbols is a vital aspect of KAM axe research, as symbols act as a medium for tracing technological knowledge and communication between distant societies—particularly when the objects themselves play an active and creative role in shaping social reality.

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NEW INSIGHTS INTO THE PRODUCTION AND EXCHANGE OF LATE BRONZE AGE KAM AXES: APPLICATION OF 3D VIEW TECHNOLOGIES

SUMMARY

In this article, we utilized 3D laser scanning and digital modeling for the first time in Bronze Age research in the Baltic countries to reconstruct clay casting molds. This innovative approach enables precise measurement of axe proportions and ornamentation, which was previously challenging due to the fragmented state of the molds. The 3D digitization process allowed for a detailed analysis of fragmented artifacts, surpassing the limitations of traditional macroscopic observations.

Using 3D models, we compared axes across regions, examining their proportions and ornamentation. This analysis revealed both shared characteristics and unique regional adaptations. Our virtual restoration techniques uncovered variations and individuality in mold designs, suggesting localized adaptations and experimentation in bronze casting.

For example, Eastern Baltic axes tend to be smaller and display fewer horizontal lines (typically three) compared to their Swedish counterparts, which commonly have four or five. These differences suggest localized production practices rather than direct replication.

Importantly, we also observe a distinct way of thinking in the Late Bronze Age, where specific symbolic codes influenced the perception of value. In the Eastern Baltic region, smaller, minimized axe forms were preferred, while maintaining the ornamental matrix. Decorative patterns, such as horizontal lines and triangular motifs, appear to have had symbolic or communicative significance. These designs were "readable" across regions, serving as markers of cultural identity and connection.

The triangular motifs found on some axes from Lithuania, Sweden, and Russia highlight cross-regional interactions and shared symbolic traditions, emphasizing the interconnectedness of these Late Bronze Age communities.

In this article, we highlighted the role of KAM axes in facilitating cultural and technological exchange across regions as distant as Scandinavia, the Eastern Baltic, and the Volga-Kama area. We propose that the standardized proportions of these axes, combined with localized decorative styles, indicate the spread of ideas rather than the direct exportation of artifacts.

This perspective calls for a reconsideration of the active role played by KAM axes in Late Bronze Age communication networks. Their proportions, ornamentation, and distribution reflect a blend of localized creativity and cross-regional connectivity. The application of 3D technologies has provided innovative insights into the technological and cultural contexts of these artifacts, offering a more nuanced understanding of their dual significance as functional tools and symbolic objects.

NAUJOS ĮŽVALGOS APIE VĖLYVOJO BRONZOS AMŽIAUS KAM KIRVIŲ GAMYBĄ IR MAINUS: 3D VAIZDO TECHNOLOGIJŲ TAIKYMAS

SANTRAUKA

Šiame straipsnyje pirmą kartą Baltijos šalių bronzos amžiaus tyrimuose panaudotas 3D lazerinis skenavimas ir skaitmeninis modeliavimas, siekiant rekonstruoti molines KAM kirvių liejimo formas. Tai leido tiksliai išmatuoti kirvių proporcijas ir ornamentiką, ko anksčiau tai buvo sudėtinga dėl formų fragmentiškumo. 3D skaitmeninimas leido atlikti detalią fragmentuotų artefaktų analizę, pranokstančią tradicinius makroskopinius stebėjimus.

Tyrime panaudoti 3D modeliai, siekiant palyginti skirtingų regionų kirvius, išryškinant jų proporcijas ir ornamentiką bei atskleidžiant tiek panašumus, tiek unikalias regionines adaptacijas.

Mūsų virtualaus restauravimo metodai atskleidė formų dizaino variacijas ir individualumą, leidžiantį kalbėti apie lokalią specifiką ir eksperimentus liejant bronzą. Rytų Baltijos šalių kirviai yra mažesni ir turi mažiau horizontalių linijų (paprastai tris) nei jų švediški atitikmenys, kurie paprastai turi keturias ar penkias. Šie skirtumai labiau pabrėžia individualistinę gamybos praktiką nei tiesioginį kopijavimą.

Tačiau kartu atsiskleidžia ir mąstymo būdas, kai vėlyvajame bronzos amžiuje daiktų vertės supratimui buvo naudojami specifiniai kodai. Rytiniame Baltijos jūros regione pirmenybė teikta minimizuotoms kirvių formoms, tačiau išlaikant ornamentinę matricą.

Atrodo, kad dekoratyviniai raštai, pavyzdžiui, horizontalios linijos ir trikampio formos motyvai, turėjo simbolinę arba komunikacinę vertę. Šiuos raštus buvo galima „perskaityti“ įvairiuose regionuose, jie buvo kultūrinio tapatumo ar ryšių žymekliai. Trikampiai motyvai ant kai kurių Lietuvos, Švedijos ir Rusijos kirvių įmovų pabrėžia tarpregioninę sąveiką ir bendras simbolines tradicijas.

Šiame straipsnyje pabrėžėme KAM kirvių vaidmenį kultūriniuose ir technologiniuose mainuose tarp tokių tolimų regionų: Skandinavijos, Rytų Baltijos ir Volgos-Kamos ir manome, kad standartizuotos kirvių proporcijos su lokalizuotais dekoratyviniais stiliais rodo veikiau idėjų sklaidą, o ne tiesioginį artefaktų eksportą.

Todėl reikia persvarstyti aktyvų KAM kirvių vaidmenį vėlyvojo bronzos amžiaus komunikacijos tinkluose, kur jų proporcijos, ornamentika ir paplitimas atspindi lokalizuoto kūrybiškumo ir tarpregioninių ryšių derinį. Naujoviškas 3D technologijų naudojimas atvėrė naujas galimybes suprasti šių artefaktų technologinį ir kultūrinį kontekstą, suteikiant niuansuotą požiūrį į jų, kaip įrankių ir simbolių, reikšmę.