ESTABLISHING A FUNCTIONAL USE FOR THE MIDDLE STONE AGE (MSA) ENGRAVED BLOMBOS OCHRE STONE THROUGH IMAGE-BASED VECTORIZATION, USE-WEAR CONSTRAINTS, AND EXPERIMENTAL RECONSTRUCTION

Silvia Stein[1], Morris Chukhman[2], and Sergii Makhin[3]

[1]Cultural Heritage, Cognitive and Digital Archaeology, Computer Applications in Archaeology (CAA)
[2]Bioengineering Research Programmer, University of Illinois Chicago, USA
[3]Cognitive Neuroscientist and Associate Professor, Berlin, Germany

ABSTRACT

An engraved ochre stone from Blombos Cave (southern Cape, South Africa) witha cross-hatched geometric motif dated to the Middle Stone Age Still Bay/M1 sequence (c. 75,000 – 77,000 years ago) is typically treated as an early abstract geometric representation without having a practical function for early humans [1]. Our case study suggests a function for the engraved ochre stone based on its proximity to evidence of fish net weights found in the Blombos cave; the perforated Nassarius Kraussianus shell net-weightsfound in the same site [1]. Building on the 2025 articlepublished in this Journal that hypothesized a functional alternative for punctured shells as string-borne net weights [1], this article focuses on the engraved ochre as related to net making and evaluates two competing hypotheses: (H1) the cross-hatched motif is a procedural template that encodes a diamond-mesh netting operation; (H0) the motif is non-procedural (decorative, symbolic, or incidental) and will not support a constraint-satisfying reconstruction as a net for shell net weights.

KEYWORDS

Blombos Cave; Engraved Ochre; Vectorization; Computational Motif Analysis; Experimental Archaeology; Nets; Material Engagement Theory.

1. INTRODUCTION

In this Journal, in 2025, Stein and Pacheco [1] re-described Nassarius shells as functional tools leading to significant shifts in the understanding of early human tool making behavior, mathematical creativity, and fishing, which European archaeologists Pauline Mouclier, Wulf Schiefenhövel, and Marian Vanhaeren cited in their 2025 article "A Study of a Traditional *Nassarius* Shell Bead Headband from the Mek Culture, Highlands of Western New Guinea: Ethnographic and Archaeological Perspectives" published in the journal *Ethnoar choreology* [2].This shift to a functional description is supported by the resemblance of the ochre engraving to a net design resemblance, done with like cross-hatch marks on the stone found in the proximity of punctured shells within the Blombos cave [1].The 2025article in this Journal[1]cross-culturally contrasted the Blombos Nassarius shells' use-wear measurements with similarly punctured shells from various prehistoric fishing sites in Florida and Puerto Rico[3], South Africa [4], and Israel [5]. **The use-wear studies [1] established that the punctured shells**

DOI : 10.5121/mathsj.2026.13201

were used as weights on a string net, though did not test for the similarity of the cross-hatch mark design in the ochre stone to the actual design of string nets that would have been used with prehistoric shells, which we test for here. The result from the previous study of shells [1] provided a functional definition for the tool use of punctured shells as net weights, with a total minimum required distributed weight of 10 grams, relying heavily on the Florida and Puerto Rico study [3]. Also, in the previous study, a visual work flow strategy, digitally producing possible reconstructions of shell weights on a fishnet, was developed and tested, providing the basis for this follow-up article testing the hypothesis (H1) that the cross-hatched motif engraved in the Blombos stone is a procedural template encoding a diamond- mesh netting operation. The null hypothesis (H0) to be disproven, and thus maintain the functional netting hypothesis (H1), is that the motif (hatch marks) is non-procedural (decorative, symbolic, or incidental) and will not support a constraint- satisfying reconstruction. Affirming the netting hypothesis (H1) by disproving the null hypothesis (H0) does not automatically disqualify other possible representational uses for the engraved ochre, though it does support H1 as a possible use.

The previous research article in this Journal [1] also descriptively and photographically bridged, using the works of cognitive experts Marlize Lombard [5] and Lyn Wadley[6], present visual cognitive style to prehistoric(fishing) sites of Skhul, Israeland Blombos, South Africa caves. Further research in theory building is required to strengthen our argument that evidence of visual communication, in stone etchings, offers clues to the expansion of brain and cognitive capacities involving the parietal lobe containing the precuneus. The precuneus is associated with spatial thinking and finger and tactile skills needed to throw a net, and judgment associated with feeling and measuring engraved ochre lines and fish net construction. In this article we continue the attempt of Lombard and Wadley [5,6] to find a correlational relationship between expansion of the parietal lobe(precuneus)and the ability to construct and use fishnets during the Middle Stone Age. Lombard (5) previously determined that human remains found in the Skhul, Israel coastal cave definetly revealed parietal lobe expansion of the skull, associated with expansion of the precuneus from 116,000 years ago. Interesting for our case study, in close proximity to the human remains artefacts in Skhul cave, Israel were also found punctured shells with string usage like at Blombos cave, South Africa. Based on the use at Blombos of punctured shells, for fishing [2], it is likelythat Blombos cave, South Africa occupants had also an evolved parietal lobe and precuneus, even though human remains have not been found in Blombos cave.

Skhul cave occupants would have been using shell net weight tools 116,000 years ago while Blombos cave occupants were using them 100,000 to 72,000 years ago [1], with both coastal areas now having further research potential for mathematical abilities in judging distance before the use of the bow and arrow.

If our net construction hypothesis (H1) is upheld as a possible use of the engraved ochre, the use of weighted fishnets having a relationship with improved cognitive abilities in spatial thinking and engineering predate by atleast 50,000 years the association of the bow and arrow (about 60,000 years ago)to improved cognitive abilities [1].

Table 1.Evolutionary indicators of bidirectional relationship between manual dexterity, testable through experimental archeology and tool reconstruction [6], and brain plasticity [5].

Neurological Metrics of the Sapient Precuneus	Functional Significance	Evolutionary Context
Chronological Range	~160,000 years ago to 100,000 years ago	Coincides with Middle Stone Age (MSA) technological

		innovations
Visuo-Spatial Integration	Bridges internal signals and external stimuli	Essential for distance based tool use with minimal physical strength involving even women
Bimanual Synchronization	Coordinates complex two handed tasks for groups or individual workers	Required for string, net and net weight making as possible first organized labor for children, disabled and elderly
Focus	Sustained attention and emotional control	For trapping out-groups of rich prey for in-group sustained brain growth in hunting/fishing

Table 2. Evidence of cranial and brain expansion related tofishing and hunting [1, 5, 6].

Development Timeline	**Estimated Date**	**Hominin Context**	**Cognitive Trait**
Globularisation of Cranium	~160,000 years ago - 100,000 years ago	H. sapiens	Expansion of Precuneus
Waterway Netting Template/Weights	~100,000 years ago - 72,000 years ago	H. sapiens	Geometric/mathe-matical reasoning for many prey
Inland Bow and Arrow Invention	~80,000 years ago - 60,000 years ago	H. sapiens	Reasoning for a single prey

A basic requirement for the invention of the bow and arrow, in central Africa 60,000 years ago, is the invention of string [1]. Use-wear studies of the punctured shells from both Skhul and Blombos caves, 116,000-100,000 years ago, establish that string was already being used for punctured shells [4] in fishing tool makingin both Mediterranean (Israel) and South African coastal regions [1]. Based on the cited evidence [4], it is likely that coastal societies preceded inland societies in string usage for tool making. The fishing tool argument relies heavily on the use-wear studies supporting that prehistoric punctured shells from the Caribbean, Mediterranean, and South Africancoastal regions were arranged horizontally on a string, hanging horizontally across [1,4], unlike a loop style for ornamental wear [3]. This could only be possible with shells, Nassarius in this case [2],being used as weights at the bottom of a fishing net [1,3]. Now, what evidence is there of fish net usage, besides the extensive evidence of fossils from fishing excavated at Blombos cave [1], in south Africa?This article presents our study on how the hatch marks, engraved in the Blombos ochre stone from about 75,000 – 77,000 years ago [7], represent the pattern required to weave a fish net.

Table 3. Evidence of Middle Stone Age use of string [1, 4, 5].

Experimental Reconstruction Parameters	**Technical Requirements**	**Archaeological Correlation**
String Diameter Supporting At Least 10g	Must fit through shell punctures	Use wear on internal shell walls
Knotting and Weaving Method	Must stabilize 10g bundles	Based on lozenge intersections on ochre
Functional Stability	Stable trammel/mesh geometry	vectorized unit cells from ochre piece M1–6/8938

The intention in our research is to build upon existing scholarly research establishing that prehistoric engraved geometric patterns in stone are not abstract forms of symbolic art [1, 7]. Instead we are establishing that these are prehistoric forms of communication, or mental extensions in the form of a motif, essential in the evolution of early mathematical engineering capacities in developing a template [7]. This study describes how the hatch mark motif is a visual, and tactile, grammar unit, a net template from the prehistoric coast of South Africa [7].

2. METHODOLOGY

A mental image, or motif, has meaning if we can recuperate its function in an artifact: a stone engraving. Recuperating lost or past meaning is retroactive, meaning that memory survives, as a mental extension, in a cognitive ability to think like in the past, if not thinking from the past. In this study we define "retroactivity" in methodological terms as a retrodictive workflow: using present material traces to constrain plausible past technical actions by iterating between (i) high-resolution documentation, (ii) digital abstraction into measurable geometries, and (iii) controlled experimental reconstruction. This is an inferential use and follows material engagement accounts (material engagement theory) of mark making as traces of action and skill [7], alongside best-practice cautions about the inferential limits of experimental archaeology [6].
Methodologically, we implement a reproducible computer assisted pipeline: (1) macro-photography of engraved surfaces (including focus stacking to increase depth of field where appropriate), (2) tablet-based re-tracing of incisions guided by published microscopic descriptions, (3) semi-automatic raster-to-vector conversion of traces into scale-calibrated polylines to enable metric analysis (cf. vectorization workflows in document digitization), and (4) quantitative motif analysis, including circular statistics of line orientations, coefficients of variation for inter-line spacing, intersection-graph topology, and unit-cell segmentation of the repeated lozenge elements. These metrics parameterize net reconstructions (string diameter; mesh angle/spacing; single-mesh versus trammel configurations), which are then assessed for mechanical plausibility under tension and weight-bearing robustness to measurement uncertainty.

3. RESULTS

Preliminary results from the vectorized dataset indicate low variance in diagonal orientations and repeated unit geometry, this is consistent with deliberate patterning reducing the space of plausible "weaving operations" to a small set of reconstructible procedures. What would falsify H1 is the inability to reproduce the motif under feasible constraints. Within the constraints using the Blombos stone as a template we were able to reproduce the motif pattern in the string net reconstructed model, justas Malafouris predicted [7].

Beyond the Blombos case study testing Malafouris' hypothesis that the engravings serve as a set of instructions, the contribution to mathematics is descriptively establishing how our earliest scripts or mental images had geometrical symmetry and proportion as a basis for our ancestors' spatial discernment and cognitive style. The other contribution to computer applications in archaeology, and digital strategies preserving heritage,is methodological: a transparent, portable vectorization andmeasurement workflow for engraved artifacts that produces reusable vector datasets (SVG/GeoJSON) suitable for comparative analysis, catalog updates, and future machineassisted pattern classification, which we shall expand upon in our next article.

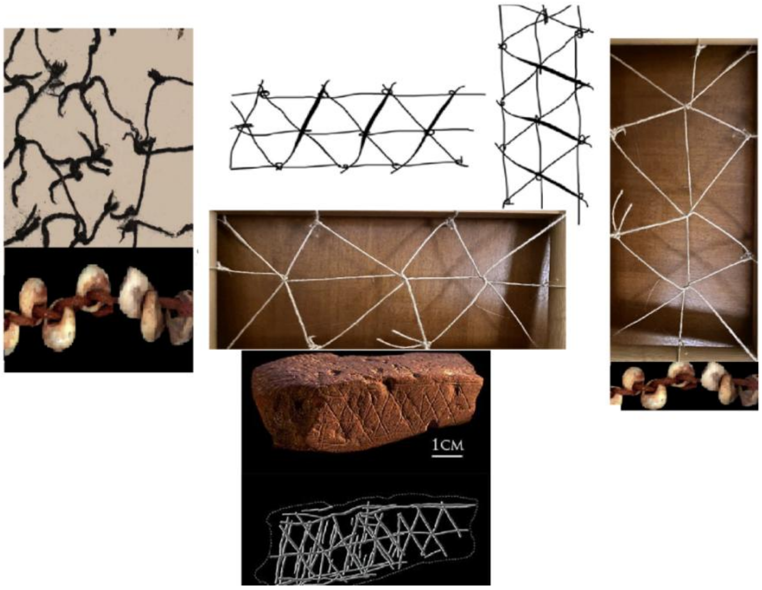

Figure 1.Workflow linking the Blombos engraved ochre to a replicable reconstruction test. Bottom: published photograph of engraved ochre piece M1–6/8938 (Blombos cave, ~75,000 – 100,000 years ago) and tracing of incision paths after prior descriptions of the motif and its production [7]. Top: this study's tablet-based re-tracing that isolates the proposed stroke order and unit geometry, followed by geometric rectification (rotation/de-skewing). Centre/right: physical string model built from the same unit geometry to evaluate whether the motif functions as a procedural template for constructing a diamond-mesh (trammel style) net under realistic constraints. Insets: punctured Nassarius shell beadwork from the broader Blombos assemblage [4] as a plausible weighting/attachment analogue [1]. Tablet tracing produces a layered, scale-referenced raster drawing that can be exported and vectorized into polylines, providing an auditable bridge between the archaeological surface [7] and the experimentally woven artefact [6].

The principal methodological risk in functional interpretations of early engravings is that the argument remains at the level of visual analogy [7]. The tabletdrawing plus vectorization workflow (Fig. 1) is designed to convert a resemblance claim ("it looks like a net") into a reproducible, falsifiable modelling exercise by (a) stabilizing the proposed geometry as data and (b) deriving explicit predictions for experimental reconstruction in archaeology (6). To really establish our net template hypothesis, further testing is required using tablet tracing to then apply the stroke order to reconstruct more alternative net models,based on the abundance of MSA engravings from the coastal cave east of Cape Town, Blombos, and west of Cape Town at Diepkloof.

For our results, involving the Blombos cave engraved ochre stone, a tablet tracing is used first because it supports controlled replication of the engraving's stroke order [7],and spatial constraints, while preserving an audit trail. This data, stroke count, stroke order, and stroke direction is then used to reconstruct a model net in experimental archaeology [6]. Working from scale calibrated photographs [1], the tracing separates individual incisions into layers and records the sequence of line production, as inferred from intersection relationships of stroke order performed by Lambros Malafouris paper and pencil [7]. Applying Malafouris' step by step paper and pencil analysis to our study, though in this case using a tablet tracing, enables systematic transformations in computer applications using tablet stored digital imagery measurements for image rotation, scaling, and de- skewing, without changing the underlying relationships among intersections. This step converts a small, irregularly preserved etched stone surface into a shareable working drawing [7] that can be inspected, digitally re-traced and stored in a computer or internet base, and thus duplicated by other researchers even for actual string based net reconstructions in experimental archaeology [6]. The Blombos engraved stone, thanks to measured digital image analysis and preservation, becomes a computer mediated model for current Middle Stone Age studies in cognitive archaeology. Our goal, in cognitive archaeology, is to understand the mental image and string design capacities of early Homo Sapiens in prehistoric net fishing coastal societies of 110,000 – 70,000 thousand years ago [1].

Vectorization then converts the tablet raster into scale-calibrated polylines (e.g., SVG/GeoJSON) suitable for quantitative analysis. Once the motif is represented as vectors, rather than just a paper and pencil study, it becomes straightforward to compute segment orientations, intersection topology, mesh aspect ratios, and spacing statistics, and to compare those metrics against competing procedural models using the same error criteria. Because vectorization is now a standard component of imageanalysis pipelines (including automated and semi-automatic approaches), the intermediate data products are portable and can be archived alongside the photographs from the previous article in this Journal [1] to support replication.

Crucially, the vector model also acts as a parametric "pattern piece" for building and testing the physical net in experimental archaeology [6] and studies of early brain evolution [5]. Intersection points translate into candidate string intersection locations in net making; unitcell dimensions constrain string length and tension; and the presence/absence of a central "trammel" line yields clear predictions about load transfer and deformation under weightsof a combined weight of 10 grams [1]. The experimental reconstruction phase [5] therefore functions as the empirical check on the computational interpretation. The engraved geometry has proven itself through testingas a usable template, the reconstructed mesh was built under realistic constraints considering string thickness, tension, and distributed 10 grams weight loading. The experimental net has a combined shell weight distribution of 10 grams which is the minimum required to sink a net in water [3], with each shell weighing a little less than 1 gram, exhibiting the proposed fishing tool functional behavior proposed in the previous article in this Journal [1] under the realistic restraints for fishing. Had our experimental reconstructed modelnet not met these restraints, failure modes such as unstable intersections, inconsistent mesh spacing, or non-viable loading would have provided direct grounds to reject or revise the hypothesis (H1), consistent with current calls for explicit controls and constraint based inference in experimental archaeology (6).

4. DISCUSSION

The implications are the occupants of the Middle Stone Age(MSA) Blombos cave not only had intellectual capacities to design, record, make and re-use string based nets, they had developed superior finger dexterity with refined engineering net construction capacities. We are making these claims based on the circumstantial evidence, the existing published expertise on these subjects in cognitive archaeology [5, 6], and the need for many more case studies testing our claims.

The development of string and netting technology represents a profound example of this finger plasticity. String could be conceived, like writing, as a visual grammar unit, that once a pattern is recognized, informs and transforms the capabilities of the hands and the cognitive style, or processing pattern, of the brain [5]. In experimental archaeology rediscovering the weaving practice with experimental reconstructions also transform our hand capabilities and cognitive style [6] to sympathize with the Blombos cave MSA occupants' ability to perceive spatial relationships and abstract sequences. If the fishing net with shell weights preceded the use of bow and arrow, as our reconstruction model suggests, it is logical to write that a string based revolution occurred much earlier than archaeologists have thought possible.

The expansion of the precuneus around 116,000to 100,000 years ago [5] aligns with the appearance of the earliest string net weight building materials at Skhul cave, Israeland at Blombos cave, South Africa. Fishing with nets might even have nurtured the early coastal migration of Homo Sapiens from South Africa to the Mediterranean, though this claim also requires further research and testing.

5. CONCLUSION

In sum, the first hypothesis (H1), that the cross-hatched motif is a procedural template [7] that encodes a diamond- mesh netting operation [1], is upheld. While the null hypothesis (H0), that the motif is non- procedural (decorative, symbolic, or incidental) and will not support a constraint- satisfying reconstruction, is not upheld in our case study. Although the cross-hatched motif might have also applications too, further testing is needed.

Our tablet tracing and macro-photography files and other raw data such as scripts, code etc. shall be included in a later article for evaluators to duplicate and evaluate our findings and results.

Tablet tracing and vectorization do not replace interpretive judgment [7]; they constrain it, document it, and make it testable by turning a motif into a measurable object and a reconstruction into a repeatable protocol.We are satisfied that our findingsseem to support cognitive archaeologist Lambros Malafouris' observation that the hatch marks engraved Blombos stone serve as both a tactile braille like reading template for the fingers, and as a visual template offering a set of instructions [7].

REFERENCES

[1] Stein, Silvia, & Susana Pacheco. 2025 "Did Fishing Nets with Calculated Shell Weights Precede the Bow and Arrow? Digitally Edited Photographs Model Another Use for Prehistoric Punctured Shells and Early Mathematical Ability." Applied Mathematics and Sciences: An International Journal (MathSJ) 12(2). DOI: https://doi.org/10.5121/MATHSJ.2025.12203

[2] Mouclier, Pauline, Schiefenhövel, Wulf, & Vanhaeren, Marian (2025) "A Study of a Traditional *Nassarius* Shell Bead Headband from the Mek Culture, Highlands of Western New Guinea: Ethnographic and Archaeological Perspectives". *Ethnoarchaeology*, 1–38. DOI: https://doi.org/10.1080/19442890.2025.2523635

[3] Keegan, Lindsay, Keegan, William, Carlson, Lisabeth, & Altes, Christopher (2009) "Shell Net Weights from Florida and Puerto Rico". *Proceedings of the XXIII Congress of the International Association for Caribbean Archaeology*, edited by S. Rebovich, Nelson's Dcokyard, Antigua, 2009.

[4] Hatton, Amy, Schoville, Benjamin, J., & Wilkins, Andrew (2020) "A Quantitative Analysis of Wear Distributions on Middle Stone Age Marine Shell Beads from Blombos Cave, South Africa". *Journal of Archaeological Science: Reports*. Volume 29, February. DOI: https://doi.org/10.1080/19442890.2025.2523635

[5] Lombard, Marlize (2024) "Bow Hunting and the Sapient Preceneus". Wynn, Thomas, Overmann, Karenleigh, and Coolidge, Frederick (Eds.) (2024). *Oxford Handbook of Cognitive Archaeology*. Oxford University Press, Oxford, England. DOI: https://doi.org/10.1093/oxfordhb/9780192895950.001.0001

[6] Wadley, Lyn. 2024 "Experimental Archaeology Enables Inferences about Human Cognition". Wynn, Thomas, Overmann, Karenleigh, and Coolidge, Frederick (Eds.) (2024). *Oxford Handbook of Cognitive Archaeology*. Oxford University Press, Oxford, England. DOI:https://doi.org/10.1093/oxfordhb/9780192895950.001.0001

[7] Malafouris, Lambros. 2021 "Mark Making and Human Becoming." Journal of Archaeological Method and Theory 28: 95–119. DOI:https://doi.org/10.1007/s10816-020-09504-4

AUTHORS

Silvia Stein completed her PhD research practicum in Strategic Communication and Psychophysiology at V.I. Vernadsky FederalCrimean University Laboratory in Simferopol, Ukraine. Her PhD practicum culminated in the 2017 published book, *Unmasking Motivation Monumentalizing Generational Trafficking Victims*, LAP LAMBERT Academic Publishing GmbH & Co. KG Heinrich-Böcking-Str. 6-8 66121, Saarbrücken, Germany. At Washington State University her PhD academic program focused on identifying, blocking, and unravelling the trends underlying human trafficking.Her MA at Washington State University focused on the biases underlying interpretation of data in Communication Studies.Her debut article in cognitive archaeology and early mathematical abilitiesis published in the*AppliedMathematics and Sciences Journal*, "Did Fishing Nets with Calculated Shell Weights Precede the Bow and Arrow? Digitally Edited Photographs Model another Use for Prehistoric Punctured Shells and Early Mathematical Ability" (June 2025, Volume 12, Number 2).Silvia Stein is a 2026 Computer Applications and Quantitative Methods in Archaeology (CAA) University of Vienna Conference Session Organizer and author, specialized in Cultural Heritage and Digital Methods in Archaeology, and Cognitive Archaeology.

Morris Chukhman, PhD studies and scientific publications focused on Bioengineering as a Research Programmer, University of Illinois Chicago, USA. Morris' top skills are Artificial Neural Network, Computer Graphics, Computing in Mathematics, Natural Science, Engineering and Medicine, Marine Biology, Applied Mathematics, Logic and Foundations of Mathematics, and Number Theory. Morris Chukhman is a 2026 Computer Applications and Quantitative Methods in Archaeology (CAA) University of Vienna Conference co-author specialized in Computational and Digital Methods in Archaeology.

Sergii Makhin,PhD, Berlin, Germany. Associate Professor. Sergii Makhin is a 2026 Computer Applications and Quantitative Methods in Archaeology (CAA) University of Vienna Conference Session Organizer, specialized in providing a Neuro-Evolutionary Framework in Cognitive Archaeology. As an extensively published expert on mirror neurons, and cognitive neuroscientist, psychologist and data analyst Sergii is passionate about applying the latest AI breakthroughs to enhance attention, learning, empathy, and cognitive health. Sergii connects neuroscience and AI to design adaptive, ethical, and human-centered intelligent systems that strengthen how we think, feel, and learn. Sergii's top skills are Data Analysis, Data Visualization, Python Programming Language, and Machine Learning.