

# Application of 2D shape analysis to study Epigravettian lithic assemblages: assessing its analytical potential

Matteo Rossini<sup>1</sup>, Armando Falcucci<sup>2</sup>, Clarissa Dominici<sup>1</sup>, Annamaria Ronchitelli<sup>1</sup>, Antonin Tomasso<sup>3</sup>, Francesco Boschin<sup>1,4</sup>

<sup>1</sup> Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, UR Preistoria e Antropologia, Università degli Studi di Siena, Via Laterino 8, 53100, Siena, Italy

<sup>2</sup> Department of Geosciences, Early Prehistory and Quaternary Ecology Working Group, Eberhard Karls University of Tübingen, Tübingen, Germany

<sup>3</sup> Université Côte d'Azur, CNRS, CEPAM, France

<sup>4</sup> CeSQ Centro Studi sul Quaternario ODV, Via Nuova dell'Ammazzatoio 7, 52037 Sansepolcro, AR, Italy

## ABSTRACT

In this paper, we apply a two-dimensional (2D) Geometric morphometric analysis to a sample of Epigravettian lithic artefacts with the aim of assessing the potential of such an approach to study Epigravettian lithic assemblages. The lithic sample comes from layer 9c2 (Evolved Epigravettian, Upper Palaeolithic, about 18,000-19,000 years ago) of Grotta Paglicci (Apulia, southern Italy). After extracting the outline coordinates from high-resolution images using the software DiaOutline, we conduct Elliptic Fourier Analysis, Principal Component Analysis, and Linear Discriminant Analysis in the R package Momocs to investigate the internal variability of the sample. Shape analysis confirms that 1) the production of microbladelets was not linked to a dedicated reduction sequence and 2) the modification of blanks into backed points followed a rather standardised stone tool design. The result opens interesting perspectives for the routine implementation of 2D shape analyses complementary to the classical technological ones.

**Section:** RESEARCH PAPER

**Keywords:** Lithic technology; Epigravettian; 2D Shape analysis; Geometric morphometrics; Upper Palaeolithic

**Citation:** Matteo Rossini, Armando Falcucci, Clarissa Dominici, Annamaria Ronchitelli, Antonin Tomasso, Francesco Boschin, Application of 2D shape analysis to study Epigravettian lithic assemblages: assessing its analytical potential, Acta IMEKO, vol. 12, no. 4, article 20, December 2023, identifier: IMEKO-ACTA-12 (2023)-04-20

**Section Editor:** Leonardo Iannucci, Politecnico di Torino, Italy

**Received** April 14, 2023; **In final form** June 27, 2023; **Published** December 2023

**Copyright:** This is an open-access article distributed under the terms of the Creative Commons Attribution 3.0 License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Funding:** This work was supported by M. Rossini's PhD Fellowship at the Doctoral School in Environmental, geological and polar sciences and technologies of the University of Siena; research of A. Falcucci is supported by the Deutsche Forschungsgemeinschaft (DFG) under grant agreement no. 431809858 (FA 1707/1-1).

**Corresponding author:** Matteo Rossini, e-mail: [m.rossini2@student.unisi.it](mailto:m.rossini2@student.unisi.it)

## 1. INTRODUCTION

The Epigravettian is an Upper Palaeolithic technocomplex attested in Italy, south-eastern France and east-west of the Balkan Peninsula and dated between c. 26-25 and 11.9-11.6 ka cal BP (thousands of years calibrated before present) [1], [2].

In Italy, the Epigravettian was originally defined and divided into three phases (i.e., early, evolved and final) by G. Laplace [3] following his systematic typological approach.

Later on, this subdivision has often been reconsidered [4]-[7]. Lithic technology has been recently used to propose a subdivision of the Epigravettian in two phases (i.e., early and late), with a chronological boundary set at around 16,000 cal BP

[8]. Discussion is however still ongoing among the research community, involving primarily the adoption of a shared model among researchers for the chrono-cultural development of this technocomplex.

Except for a few notable cases [9]-[11], southern Italian Epigravettian lithic assemblages have been exclusively analysed following a typological approach [4]. In central-northern Italy, assemblages have been instead studied using a modern approach, which complement typology with an accurate reconstruction of the procedures involved in the production of blanks [5], [7],[8], [12]-[15].

According to some researchers, an intermediate phase of the Epigravettian (Evolved Epigravettian) would be attested in southern Italy [4]-[16], whereas it is no longer recognised towards northern Italy.

The so-called Evolved Epigravettian was defined on the basis of typological evidence, mainly due to the presence of retouched lithic artefacts that define both the early and final phases of Epigravettian [4]-[18]. The main features are the following:

- long end-scrapers prevail over the short ones (characteristic of the final phase);
- triangular end-scrapers appear (characteristic of the Final Epigravettian);
- shouldered pieces decrease (characteristic of the Early Epigravettian);
- the retouched artefacts have a reduction in size with respect to Early Epigravettian.

In the light of the discussion summarised above, we argue that it is important to design new studies integrating typological, technological, and geometric morphometrics approaches. Concerning the latter approach, it should be mentioned that lithic artefacts do not have clear homologous loci of geometric significance. The use of landmarks and semilandmarks required for geometric morphometrics analysis is therefore challenging. On the other hand, a time-effective and reliable alternative to a landmark-based approach is outline analysis [19]-[20], which has been often used to investigate variability in prehistoric lithic implements.

Quantification of shape outlines is in most cases conducted on retouched artefacts, while unretouched laminar products have received little attention. In the case of the Epigravettian, shape analysis has yet to be used for the study of both retouched and unretouched artefacts. In this paper, we will thus explore the use of shape analysis to help answer questions on the production and modification of laminar artefacts. Recent studies carried out on an Upper Palaeolithic laminar assemblage have highlighted the potential of combining the quantification of shape with technological assessments [21]-[22].

Concerning the use of this approach in the study of backed tools, its potential has been demonstrated by several scholars that have pursued questions on the diffusion of specific elements through time and space and the interrelation between morphology and techniques applied during production processes [22]-[25].

Our contribution is to be considered a preliminary step in framing the issues surrounding the Epigravettian technocomplex, combining lithic typology with a techno-economic approach [26]-[28]. To do so, it is necessary to proceed with the study of each individual lithic element to trace it back to a specific phase of the reduction sequence and technical event to interpret the site's function and its socio-economic role [27]. To this end, from the beginning of the study, it is essential to carry out an analysis integrating different analytical methods [28], namely petrography, technology, and use-wear analysis.

The study of the entire lithic assemblage from layer 9c2 at Grotta Paglicci is currently underway and it will then be extended to other layers, to understand whether the technical behaviour commonly defined as Evolved Epigravettian exists in southern Italy and can be distinguished from the rest of the identified phases.

## 2. MATERIALS AND METHODS

This paper focuses on the Evolved Epigravettian layer 9c2 of Grotta Paglicci, a key site for the Palaeolithic of Mediterranean Europe. Grotta Paglicci (Rignano Garganico – Foggia, Figure 1) opens on the southern slopes of the Gargano Promontory at 143 m a. s. l. [29]. The cave yielded an important Upper Palaeolithic stratigraphic sequence spanning from the Aurignacian to the Final Epigravettian (i.e., from about 40 to about 11.5 ka BP) [29]. New multidisciplinary investigations with both traditional and innovative techniques are currently being carried out by the University of Siena under the direction of professor Francesco Boschini [29]-[40].

The material analysed in this paper is a sample composed of complete laminar and lamellar blanks and retouched artefacts (Figure 2). Available  $^{14}\text{C}$  dates for the whole layer 9 point to a chronology between ca. 19 and 18.5 ka cal BP [29].

The dataset contains 49 items belonging to different classes and technological categories. The sample was analysed using a technological-typological approach [26], [41] and each artefact was attributed to a specific reduction sequence and phase (i.e., initialization, maintenance, and full production). Table and boxplots were designed in PAST 4.03. [42].

In order to conduct a shape outline study, we took pictures of each implement in dorsal view and oriented according to the flaking axis. The camera was levelled using a spirit level to maintain a stable photo configuration throughout the data recording. We laid all artefacts on a surface with a contrasting, white-coloured background. Furthermore, we avoided distortion by levelling flat all artefacts, even using sand when necessary. To minimise the parallax error, each artefact was centred within the camera frame. Lastly, the positioning of the lights was done with the main goal of reducing shadows around the artefact, speeding up data processing. The steps aforementioned are also

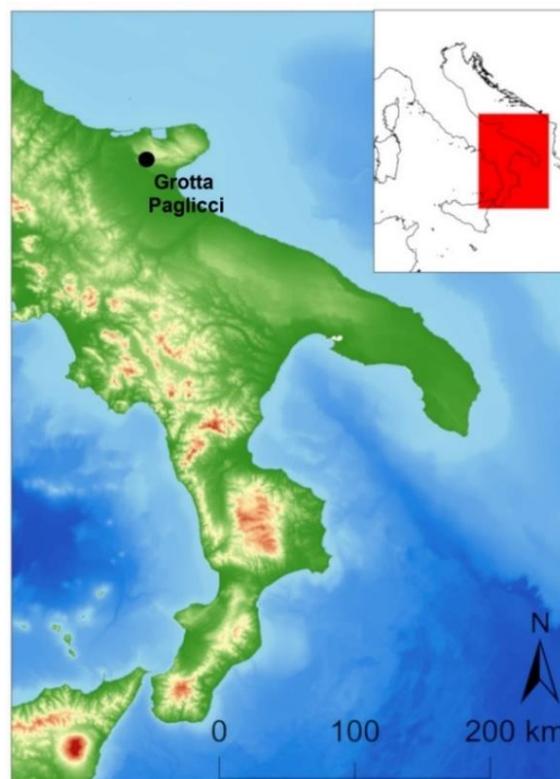


Figure 1. Location of Grotta Paglicci



Figure 2. At the top, some examples of laminar and lamellar blanks are shown, at the bottom we find retouched artefacts, from layer 9c2.

described in a recent inter-observer reliability test on artefact photography and 2D shape analysis [43].

We first imported all photos to Adobe Photoshop to remove the background and facilitate the following outline extraction. The latter was done in the open-source software DiaOutline [44], which allows to automatically extract the x and y coordinate vector metric for each artefact's outline. The software's user-friendly graphical interface allows to follow a systematic workflow for data collection and analysis that can be performed in a linear sequence, as discussed by A. Wishkerman et al. (2018) [44].

DiaOutline saves coordinates in single .txt files, which were then imported in R [45] to conduct shape analysis in the package *Momocs* [46]. We followed all required steps to centre, scale, and rotate the outlines, prior to performing Elliptic Fourier Analysis (EFA)(Figure 3). This methodology was first developed by Kuhl and Giardina (1982) [47] and it allows to measure contour shape variations thanks to terms of sine and cosine curves of successive frequencies (i.e., harmonics). We used the number of harmonics that describe the 99.9 % of the harmonic power. Principal Component Analysis (PCA) was then performed on the Fourier coefficients to reduce data dimensionality and explore shape changes across the sample. The PCA allows in fact to transform linearly correlated data into non-variables correlates, called principal components [48]. We have chosen to use PCA because it allows us to simplify patterns of variation and covariation of an artefact's shape in a space with low dimensionality [49]. After assessing the cumulative importance of each PC following the screen-plot technique [50], we decided to focus on the first three principal components (PCs) to further explore shape differences.

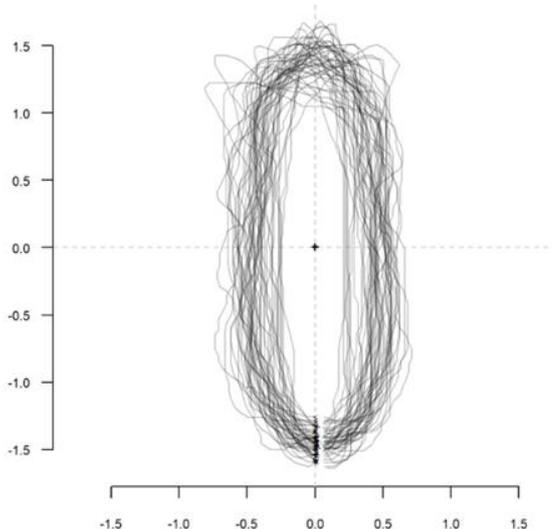


Figure 3. All outlines of lithic implements centred and scaled.

We also used Linear Discriminant Analysis (LDA) implemented in *Momocs* [46] to further explore variability. Lastly, we used the first three PC scores to conduct a PERMANOVA test in R [45] and we designed bivariate plots in the R package *ggplot2* [51] for data visualization purposes.

### 3. RESULTS

All analysed artefacts are made on chert and, from a metrical point of view, can be assigned to three different categories: blades, bladelets, and microbladelets.

The main results of the technological analysis are shown in Table 1. The sample consists of 41 unretouched blanks (23 blades, 10 bladelets, and 8 microbladelets) and 8 retouched artefacts.

The latter are 4 backed points (PD4 following Laplace's analytical typological) and 4 common tools (two end-scrapers, one bec, and one side-scraper).

All common tools were obtained from blades, whereas the backed points were obtained from bladelets. The backed points are characterised by one continuous back along the entire lateral edge, delineated thanks to a deep and direct retouch. Only in one case the back is made by alternating direct-inverse, abrupt retouch. Two backed points are characterised by a complementary retouch located in the apical portion, the first being inverse and flat, while the second being semi-abrupt

Table 1. Technological classes and categories divided according to reduction sequences. Init: initialization; Man: maintenance; Full prod: production

	Init.	Man.	Full prod.	Total
<b>Backed point</b>	<b>1</b>	-	<b>3</b>	<b>4</b>
Bladelet	1	-	3	4
<b>Tool</b>	<b>1</b>	<b>2</b>	<b>1</b>	<b>4</b>
Blade	1	2	1	4
<b>Blank</b>	<b>3</b>	<b>24</b>	<b>14</b>	<b>41</b>
Blade	1	19	3	23
Bladelet	-	4	6	10
Microbladelets	2	1	5	8
<b>Total</b>	<b>5</b>	<b>26</b>	<b>18</b>	<b>49</b>

marginal. The latter was implemented to make a pointed apex, whereas the former was implemented to thin the extremities.

Figure 4 reports the metric attributes of all unretouched and retouched artefacts (length, width, thickness).

Figure 5 displays the shape variation explained by the first three PCs. PC1, which explains ca. 63 per cent of the total variance, refers mostly to artefacts' elongation and slenderness. Shape variation ranges from the stouter artefacts found in the negative scores of PC1, up to the more elongated artefacts towards the positive scores of PC1, up to the more elongated artefacts towards the positive scores. Despite PC2 and PC3 explain a lower percentage of variation, shape changes are related to important shape variability in lithic analysis, such as the degree of distal asymmetry and broadness of the apex.

PC2 positive scores show pieces with acute/convergent edges. PC2 negative scores exhibit pieces with a wide apex. Interestingly, PC3 positive scores are comparable to the negative scores of PC2.

We assessed differences in the studied sample using a PERMANOVA test on the first three PCs, finding a significant variation ( $F = 8.208, p < 0.01$ ). The PCA plot in Figure 6 shows in fact a clear cluster formed by all backed points, which plot close to each other in the negative extreme of PC1. On the other

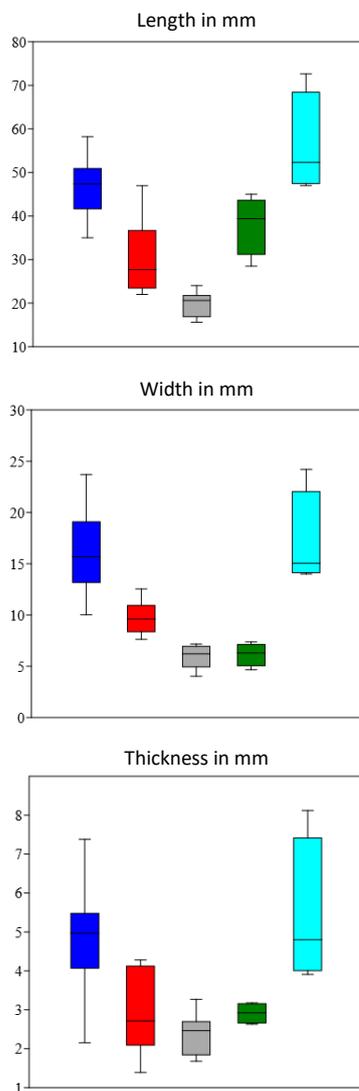


Figure 4. Boxplot showing the distribution (in mm) of length, width, and thickness in blades (blue), bladelets (red), microbladelets (grey), backed tools (green), and tools (cyan).

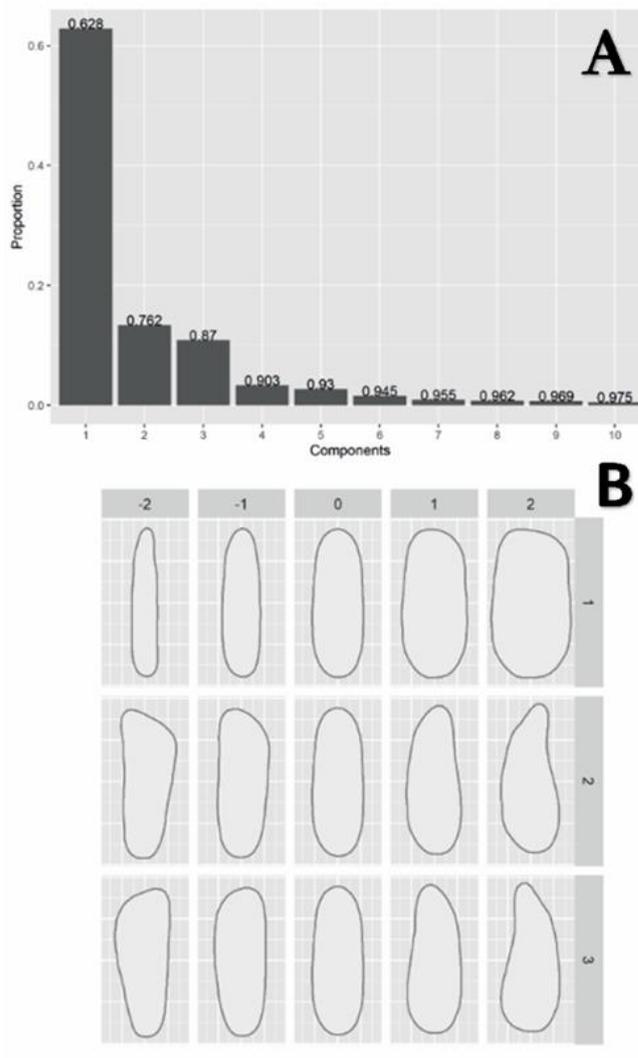


Figure 5. Results of the 2D shape analysis: A displays the proportion of variance explained by the first ten principal components. B presents the shape variation of the first three principal components.

hand, the blank class occupies a larger portion of the PCA space, highlighting a significant variance within this group, being formed of blanks belonging to different stages of the core reduction. These results are in line with the observed low variability for backed points, which indeed form a highly homogeneous cluster compared to the rest of the groups. In our opinion, this is mostly linked to the highly standardised nature of backed points, which were selected and further modified according to a specific tool design.

Common tools, on the other hand, show higher variability and this is dictated by the fact that they are not all attributable to the same typological group or function. They were also obtained from blanks belonging to different production stages.

As a final assessment of the shape variability identified, we performed a LDA and Figure 7 displays results after a leave-one-out cross-validation. Overall, almost 80 % of the analysed sample has been correctly classified; all the backed points have been correctly classified.

Interestingly, one narrow bladelet blank (ID 408) has been classified as a backed point. Its shape, size, and some technological attributes (the trapezoidal cross-section, and the flat bulb) suggest that this artefact could have been selected to

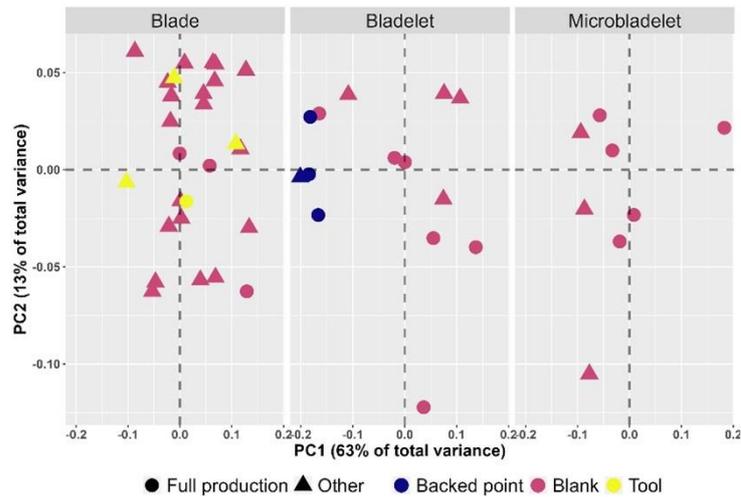


Figure 6. Bivariate plots of the first two principal components (PC1 versus PC2) divided according to blank class. Artefacts are divided according to the classes discussed in the paper. The triangles (Other) refer to those blanks belonging to initialization and maintenance, while the circles to the full production stage. See legend for colours.

manufacture a backed point with little investment in the retouching of the back (Figure 8). This assumption changes if we consider that the delineation of the ventral profile is wavy: for this last technological characteristic, we can suggest that this blank was discarded and not used despite its performant shape. Despite this interesting case, our results suggest that the shape of Epigravettian backed points was drastically modified during the retouching phase, although we underline that it will be necessary to implement this data with the ongoing study of the entire lithic assemblage to better understand Epigravettian behaviour in relation to the manufacture and use of backed points.

The ongoing technological study showed that there is no dedicated reduction sequence linked to the production of the microbladelets. The data obtained from shape analysis confirm this assumption and led us to merge the two categories into a single one, as they do not reveal a clear variation in shape across technological categories. Table 2 lists the metric attributes of the unretouched assemblage according to this new consideration.

In order to further corroborate the expected differences, we performed a Mann–Whitney independent sample test to see if their division into blade and bladelet categories is metrically consistent. The test shows that there are significant differences in length (Mann–Whitney,  $U = 16$ ;  $p < 0.01$ ), width (Mann–Whitney,  $U = 5$ ;  $p < 0.01$ ), and thickness (Mann–Whitney,  $U = 38$ ;  $p < 0.01$ ).

#### 4. DISCUSSION AND CONCLUSION

Based on metric considerations, we initially proposed to distinguish bladelets from microbladelets in the studied assemblage. However, as mentioned above, the distinction of these two categories was no longer maintained, as in layer 9c2 microbladelets were not produced through a specific reduction sequence and did not have specific shape.

The results of the shape analysis show that there is no predetermination in the production of lamellar blanks to obtain

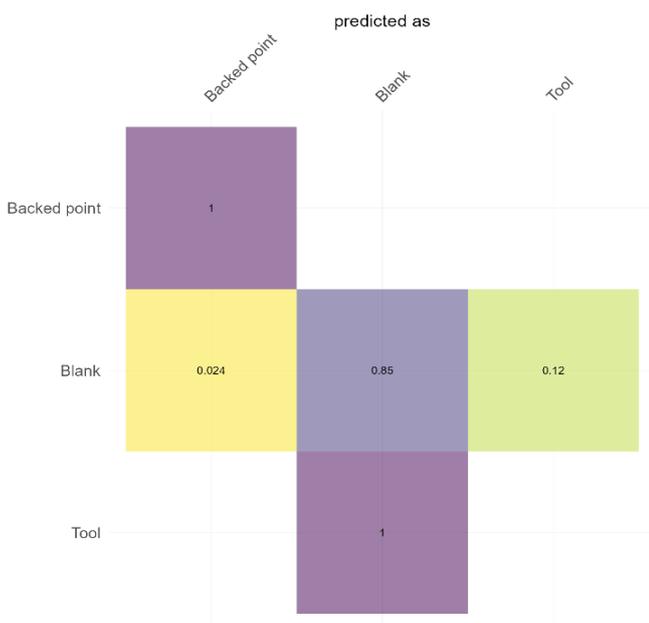


Figure 7. Results of cross-validation tests over LDA inputs. The rows show the class of artefacts and the columns show the prediction.



Figure 8. On the left side backed point (PD4, ID 32), and on the right side the bladelet (ID 408).

Table 2. Descriptive statistics of the metric attributes of blades and bladelets. Linear measurements are in millimetres. Abbreviations: SE, standard error; SD, standard deviation.

	Range	Mean	SE	SD	25 percentile	Median	75 percentile
<b>Blade (n = 23)</b>							
Length	35.0 to 58.2	46.5	1.3	6.4	41.6	47.4	50.9
Width	10.0 to 23.7	16.1	0.8	3.7	13.2	15.7	19.1
Thickness	2.2 to 7.4	4.9	0.3	1.3	4.1	5.0	5.5
<b>Bladelet (n = 18)</b>							
Length	15.6 to 47.0	25.5	1.9	8.1	20.6	23.2	29.2
Width	4.0 to 10.0	8.0	0.6	2.3	6.2	7.7	9.7
Thickness	1.4 to 4.3	2.7	0.2	0.9	2.1	2.5	3.4

backed points. The latter form a specific cluster with a recurring morphology, and the shape is obtained mainly through retouching. However, these last hypotheses have to be backed up by an in-depth technological analysis of the entire lithic assemblage.

In this work, we explored the potential of applying 2D shape outline analysis to an Epigravettian assemblage. This analysis allowed us to quantify the difference between shape outlines of common tools, laminar blanks, and backed points and to discuss the technological implications of such variability.

Our future aim is to increase the sample size to conduct a comprehensive and dedicated study on the different shape morphologies of the blanks belonging to the optimal production phase and linked to different reduction sequences. After adding new artefacts to this dataset, a following study will also allow to compare lithic variability across several Epigravettian lithic assemblages.

A further goal for future research will be to quantify other technological characteristics such as the cross-section of artefacts. To obtain this data we can use the same methodology explained in this work, but first, we have to collect 3D data using the increasingly affordable scanning technology, ranging from photogrammetry [52]-[53] to structured light laser scanners [54]. By doing so, it will be possible to segment artefacts and extract cross-section data, following a recent application [22].

Our last objective will be to compare the production and modification of backed points across chronologically and geographically differentiated Epigravettian contexts. In this framework, it will be important to comprehend the technological variability of backed points to be able to sort finished items from those backed points that were discarded prior to the final retouching phases.

The methodology used in this work opens important perspectives for the routinary implementation of morphological analyses complementary to the technological assessment.

These analyses will support, complete and clarify the qualitative observations that form the basis for the definition of the different techno-economic groups within lithic assemblages.

## ACKNOWLEDGEMENTS

We are grateful to Soprintendenza Archeologia Belle Arti e Paesaggio per le Province di Foggia, Barletta e Trani for granting permission to study the material. We are likewise grateful to Prof. Arturo Palma di Cesnola, from whose important research at Grotta Paglicci the material studied was derived. A special thanks to Stefano Ricci for the photos.

This study was carried out at the Department of Physical Sciences, Earth and Environment of the University of Siena.

This work is part of the PhD project of Matteo Rossini “Pratiche venatorie e dinamiche comportamentali dei gruppi gravettiani ed epigravettiani del Sud Italia. Analisi tecnologica e ricostruzione delle catene operative delle armature litiche dei siti di Grotta Paglicci e Grotta della Cala”.

A. Falcucci’s research was supported by the Deutsche Forschungsgemeinschaft (DFG) under grant agreement no. 431809858-FA 1707/1-1.

## REFERENCES

- [1] N. Naudinot, A. Tomasso, C. Tozzi, M. Peresani, Changes in mobility patterns as a factor of 14C date density variation in the Late Epigravettian of Northern Italy and Southeastern France, *J. Archaeol. Sci.* 52 (2014), pp. 578-590. DOI: [10.1016/j.jas.2014.05.021](https://doi.org/10.1016/j.jas.2014.05.021)
- [2] A. Ruiz-Redondo, N. Vukosavljević, A. Tomasso, M. Peresani, W. Davies, M. Vander Linden, Mid and Late Upper Palaeolithic in the Adriatic Basin: Chronology, transitions and human adaptations to a changing landscape, *Quat. Sci. Rev.* 276 (2022), art. No. 107319. DOI: [10.1016/j.quascirev.2021.107319](https://doi.org/10.1016/j.quascirev.2021.107319)
- [3] G. Laplace, Les subdivisions du leptolithique italien: étude de typologie analytique, *Bullettino di Paleontologia Italiana* 15 (1964), pp. 25-63. [In French]
- [4] A. Palma di Cesnola, *Il Paleolitico Superiore in Italia: Introduzione allo Studio*, Garlatti e Razzai, Firenze, Italia, 1993. [In Italian]
- [5] C. Montoya, *Les traditions techniques lithiques à l'Épigravettien: Analyses de séries du Tardiglaciaire entre Alpes et Méditerranée*, PhD Thesis, Université de Provence - Aix-Marseille I, 2004. [In French]
- [6] A. Broglio, *Considérations sur l'Épigravettien italien*, J. M. Fullola, N. Soler (Eds.), *El Món Mediterrani Després Del Pleniglacial (18000-12000 BP)*, Museu d'Arqueologia de Catalunya, Girona, 1997, pp. 147-158. [In French]
- [7] A. Tomasso, *Territoires, systèmes de mobilité et systèmes de production. La fin du Paléolithique supérieur dans l'arc liguro-provençal*, PhD Thesis, Université Nice Sophia-Antipolis & Università di Pisa, 2014. [In French]
- [8] A. Tomasso, *L'épigravettien: variabilité diachronique et géographique*, M. Olive (Ed.), *Campo Delle Piane: Un Habitat de Plein Air Épigravettien Dans La Vallée Du Gallero (Abruzzes, Italie Centrale)*, École Française de Rome, Rome, 2017, pp. 13-21. [In French]
- [9] G. Ricci, M. V. Conesa, F. Martini, Through diachronic discontinuities and regionalization: The contribution of the analysis of the lithic industries from Grotta della Serratura (Strata 10-9) in the definition of Epigravettian in the southern Italian peninsula, *J. Archaeol. Sci. Rep.* 24 (2019), pp. 175-191. DOI: [10.1016/j.jasrep.2018.11.038](https://doi.org/10.1016/j.jasrep.2018.11.038)
- [10] E. Cancellieri, *L'Epigravettiano antico a punta a cran dell'area di Fondo Focone presso Ugento (Salento meridionale ionico) nel quadro della frequentazione dell'Italia peninsulare adriatica alla*

- fine dell'Ultimo Massimo Glaciale, in: F. Radina (Ed.), *Preistoria e Protostoria Della Puglia*, 2017. [In Italian]
- [11] M. Rossini, A. Falcucci, C. Dominici, A. Ronchitelli, A. Tomasso, F. Boschin, Analytical potential of 2D shape analysis to study Epigravettian lithic assemblages, *Proc. of the 2022 IMEKO TC-4 Int. Conf. on Metrology for Archaeology and Cultural Heritage*, Consenza, Italy, 19-21 September 2022. DOI: [10.21014/tc4-ARC-2022.011](https://doi.org/10.21014/tc4-ARC-2022.011)
- [12] R. Duches, M. Peresani, P. Pasetti, Success of a flexible behavior. Considerations on the manufacture of Late Epigravettian lithic projectile implements according to experimental tests, *Archaeol. Anthropol. Sci.* 10(7) (2018), pp. 1617-1643. DOI: [10.1007/s12520-017-0473-x](https://doi.org/10.1007/s12520-017-0473-x)
- [13] F. Fontana, A. Guerreschi, S. Bertola, M.G. Cremona, F. Cavulli, L. Falceri, A. Gajardo, C. Montoya, M. Ndiaye, D. Visentin, "I livelli più antichi della serie epigravettiana "interna" di Riparo Tagliente: sfruttamento delle risorse litiche e sistemi tecnici", in: G. Leonardi, V. Tiné (Eds.), *Preistoria e Protostoria Del Veneto*, 2015, pp. 43-52. [In Italian]
- [14] E. Cancellieri, From the watershed to the Great Adriatic Plain: an investigation on humans and landscape ecology during the late Upper Paleolithic. The significance of lithic technology, PhD thesis, Università degli Studi di Ferrara, 2010.
- [15] N. Fasser, D. Visentin, F. Fontana, Characterising Late Palaeolithic manufacturing traditions: backed points production methods in the Late Epigravettian sequence of Riparo Tagliente (NE Italy), *J. Archaeol. Sci. Rep.* 22 (2023), art. No 103343. DOI: [10.1016/j.jasrep.2022.103343](https://doi.org/10.1016/j.jasrep.2022.103343)
- [16] S. Blockley, M. Pellegrini, A.C. Colonese, D. Lo Vetro, P.G. Albert, A. Brauer, Z. Di Giuseppe, A. Evans, P. Harding, J. Lee-Thorp, P. Lincoln, F. Martini, M. Pollard, V. Smith, R. Donahue, Dating human occupation and adaptation in the southern European last glacial refuge: The chronostratigraphy of Grotta del Romito (Italy), *Quat. Sci. Rev.* 183(2018), pp. 5-25. DOI: [10.1016/j.quascirev.2017.09.007](https://doi.org/10.1016/j.quascirev.2017.09.007)
- [17] A. Palma di Cesnola, Le industrie di Grotta Paglicci (Rignano Garganico-FG): strati 9-8 (scavi A. Palma di Cesnola 1973-75). *Rassegna di Archeologia* 23A (2011), pp. 11-54. [In Italian]
- [18] A. Palma di Cesnola, L'Epigravettiano Evoluto degli strati 10 e 11 di Paglicci, *Rassegna di Archeologia* 25, 2017. [In Italian]
- [19] F. J. Rholff, Fitting curves to outlines, in: *Proc. of the Michigan Morphometrics Workshop*. F. J. Rholff, F. L. Bookstein (editors). The University of Michigan Museum of Zoology, Arbor, Michigan, 1992, pp. 167-177.
- [20] D. N. Matzig, S. T. Hussain, F. Riede, Design Space Constraints and the Cultural Taxonomy of European Final Palaeolithic Large Tanged Points: A Comparison of Typological, Landmark-Based and Whole-Outline Geometric Morphometric Approaches, *J. Paleolit. Archaeol.* 4(27) (2021). DOI: [10.1007/s41982-021-00097-2](https://doi.org/10.1007/s41982-021-00097-2)
- [21] A. Falcucci, F.A. Karakostis, D. Goldner, M. Peresani, Bringing shape into focus: Assessing differences between blades and bladelets and their technological significance in 3D form, *J. Archaeol. Sci. Rep.* 43 (2022), art. No. 103490. DOI: [10.1016/j.jasrep.2022.103490](https://doi.org/10.1016/j.jasrep.2022.103490)
- [22] A. Falcucci, M. Peresani, The contribution of integrated 3D model analysis to Protoaurignacian stone tool design, *Plos One* 17(5) (2022), art. No. e0268539. DOI: [10.1371/journal.pone.0268539](https://doi.org/10.1371/journal.pone.0268539)
- [23] M. Way, P. de la Peña, E. de la Peña, L. Wadley, Howiesons Poort backed artifacts provide evidence for social connectivity across southern Africa the Final Pleistocene, *Sci. Rep.* 12(1) (2022), art. No. 9227. DOI: [10.1038/s41598-022-12677-5](https://doi.org/10.1038/s41598-022-12677-5)
- [24] I. Schmidt, *Solutrean Points of the Iberian Peninsula: tool making and using behaviour of hunter-gatherers during the Last Glacial Maximum*, BAR International Series 2778, Oxford, UK, 2015.
- [25] A. Maier, R. John, F. Linsel, G. Roth, Wa. Antl Weiser, L. Bauer, N. Buchinger, L. Cavak, H. Hofmann, J. Puschmann, M. Schemmel, V. C. Schmid, U. Simon, R. Thomas, Trends in Material Culture Evolution—a Case Study of Gravettian Points from Lower Austria and Moravia. *J. Paleo Arch* 6(15) (2023). DOI: [10.1007/s41982-023-00145-z](https://doi.org/10.1007/s41982-023-00145-z)
- [26] M. L. Inizan, M. Reduron, H. Roche, J. Tixier, *Technology and terminology of knapped stone: followed by a multilingual vocabulary Arabic, English, French, German, Greek, Italian, Portuguese, Spanish*, 5th ed., Cercle de recherche et d'études préhistoriques - CREP, Nanterre, France, 1999
- [27] J.-M. Geneste, *Systèmes techniques de production lithique. Variations techno-économiques dans les processus de réalisation des outillages paléolithiques. Techniques & Culture* 54-55 (2010), pp. 419-449. [In French]
- [28] A. Tomasso, V. Rots, Looking into Upper Paleolithic gear: the potential of an integrated techno-economic approach. *J. Anthropol. Archaeol.* 61 (2021), 101240. DOI: [10.1016/j.jaa.2020.101240](https://doi.org/10.1016/j.jaa.2020.101240)
- [29] F. Boschin, P. Boscato, C. Berto, J. Crezzini, A. Ronchitelli, The palaeoecological meaning of macromammal remains from archaeological sites exemplified by the case study of Grotta Paglicci (Upper Palaeolithic, southern Italy), *Quat. Res.*, vol. 90 (2018), No. 3, pp. 470-482. DOI: [10.1017/qua.2018.59](https://doi.org/10.1017/qua.2018.59)
- [30] F. Boschin, F. Bernardini, E. Pilli, S. Vai, C. Zanolli, A. Tagliacozzo, R. Fico, M. Fedì, J. Corny, D. Dreossi, M. Lari, A. Modi, C. Vergata, C. Tuniz, A. Moroni, P. Boscato, D. Caramelli, A. Ronchitelli, The first evidence for Late Pleistocene dogs in Italy, *Scientific Reports* 10 (2020), 13313. DOI: [10.1038/s41598-020-69940-w](https://doi.org/10.1038/s41598-020-69940-w)
- [31] F. Boschin, Exploitation of carnivores, lagomorphs and rodents at Grotta Paglicci during the Epigravettian: The dawn of a new subsistence strategy?, *Journal of Archaeological Science: Reports* 26 (2019), 101871. DOI: [10.1016/j.jasrep.2019.101871](https://doi.org/10.1016/j.jasrep.2019.101871)
- [32] F. Lugli, A. Cipriani, G. Capecchi, S. Ricci, F. Boschin, P. Boscato, P. Iacumin, F. Badino, M. A. Mannino, S. Talamo, M. P. Richards, S. Benazzi, A. Ronchitelli, Strontium and stable isotope evidence of human mobility strategies across the Last Glacial Maximum in southern Italy. *Nature Ecology and Evolution* 3 (2019) 6, pp. 905-911. DOI: [10.1038/s41559-019-0900-8](https://doi.org/10.1038/s41559-019-0900-8)
- [33] C. Berto, P. Boscato, F. Boschin, E. Luzi, A. Ronchitelli, Palaeoenvironmental and paleoclimatic context during the Upper Palaeolithic (late Upper Pleistocene) in the Italian Peninsula. The small mammal record from Grotta Paglicci. (Rignano Garganico, Foggia, Southern Italy), *Quaternary Science Review*, 168 (2017), pp. 30-41. DOI: [10.1016/j.quascirev.2017.05](https://doi.org/10.1016/j.quascirev.2017.05)
- [34] S. Ricci, G. Capecchi, F. Boschin, S. Arrighi, A. Ronchitelli, S. Condemi, Toothpick use among Epigravettian humans from Grotta Paglicci (Italy). *International Journal of Osteoarchaeology*, 26 (2016) 2, pp. 281-289. DOI: [10.1002/oa.2420](https://doi.org/10.1002/oa.2420)
- [35] V. Borgia, F. Boschin, A. Ronchitelli, Bone and antler working at Grotta Paglicci (Rignano Garganico, Foggia, southern Italy). *Quaternary International*, 403 (2016), pp. 23-39. DOI: [10.1016/j.quaint.2015.11.116](https://doi.org/10.1016/j.quaint.2015.11.116)
- [36] A. Ronchitelli, S. Mugnaini, S. Arrighi, A. Atrei, G. Capecchi, M. Giamello, L. Longo, N. Marchettini, C. Viti, A. Moroni, When technology joins symbolic behaviour: the Gravettian burials at grotta Paglicci (Rignano Garganico e Foggia - Southern Italy), *Quat. Int.* 359 (2015), pp. 423-441. DOI: [10.1016/j.quaint.2014.08.038](https://doi.org/10.1016/j.quaint.2014.08.038)
- [37] A. Modi, S. Vai, C. Posth, C. Vergata, V. Zaro, M. A. Diroma, F. Boschin, G. Capecchi, S. Ricci, A. Ronchitelli, G. Catalano, G. Lauria, More data on ancient human mitogenome variability in Italy: new mitochondrial genome sequences from three Upper Palaeolithic burials, *Ann. Hum. Bio.*, 48 (2021), pp. 213-222. DOI: [10.1080/03014460.2021.1942549](https://doi.org/10.1080/03014460.2021.1942549)
- [38] C. Dominici, C. Stani, M. Rossini, L. Vaccari, SR-FTIR microscopy for the study of residues on Palaeolithic stone tools:

- looking for a methodological protocol, *J. Phys. Conf. Ser.* 2204 (2022), art. No. 012050.  
DOI: [10.1088/1742-6596/2204/1/012050](https://doi.org/10.1088/1742-6596/2204/1/012050)
- [39] C. Dominici, C. Stani, V. Bonanni, M. Rossini, I. Božičević Mihalić, G. Provas, S. Fazinić, F. Boschin, A. Gianoncelli, L. Vaccari, Combining SR-FITR, SR-LEXRF and PIXE microscopies for residue analysis on Palaeolithic stone artefacts. *European Physical Journal Plus* 138 (2023), 742.  
DOI: [10.1140/epjp/s13360-023-04320-7](https://doi.org/10.1140/epjp/s13360-023-04320-7)
- [40] C. Posth, H. Yu, A. Ghalichi (+ another 122 authors), Palaeogenomics of Upper Palaeolithic to Neolithic European hunter-gatherers, *Nature* 615 (2023), pp. 117–126.  
DOI: [10.1038/s41586-023-05726-0](https://doi.org/10.1038/s41586-023-05726-0)
- [41] G. Laplace, *Essai de typologie systématique*, *Annali dell'Università di Ferrara, Università degli Studi di Ferrara, n.s., sez. XV, suppl. II vol.I, Italia, 1964*, pp. 1-85. [In Italian]
- [42] Ø. Hammer, D. A. T. David, P. D. Ryan, Past: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, 4(1) (2001). Online [Accessed 25 August 2023]  
[https://palaeo-electronica.org/2001\\_1/past/past.pdf](https://palaeo-electronica.org/2001_1/past/past.pdf)
- [43] L. Timbrell, A collaborative model for lithic shape digitization in museum settings. *Lithic Technology*, 48 (2022) 1, pp. 31–42.  
DOI: [10.1080/01977261.2022.2092299](https://doi.org/10.1080/01977261.2022.2092299)
- [44] A. Wishkerman, P. B. Hamilton, Shape outline extraction software (DiaOutline) for elliptic Fourier analysis application in morphometric studies, *APPS* 6(12) (2018), art. no. e01204–e.  
DOI: [10.1002/aps3.1204](https://doi.org/10.1002/aps3.1204)
- [45] R Core Team, R: A language and environment for statistical computing, R Foundation for statistical computing, Austria, 2020.
- [46] V. Bonhomme, S. Picq, C. Gaucherel, J. Claude, Momocs: Outline analysis using R, *J. Stat. Softw.* 56(13) (2014), pp.1-24.  
DOI: [10.18637/jss.v056.i13](https://doi.org/10.18637/jss.v056.i13)
- [47] F. P. Kuhl, C. R. Giardina, Elliptic Fourier features of a closed contour. *Computer Graphics and Image Processing*, 18(3), pp. 236–258.  
DOI: [10.1016/0146-664X\(82\)90034-X](https://doi.org/10.1016/0146-664X(82)90034-X)
- [48] K. Pearson, On lines and planes of closest fit to systems of points in space, *Philosophical Magazine* 2 (6) (1901), pp. 559-572
- [49] M. L. Zelditch, D. L. Swiderski, D. H. Sheets, W. L. Fink, *Geometric Morphometrics for Biologist. A Primer*. New York: Elsevier Academic Press, 2004, ISBN: 978-0-12-778460-1
- [50] A. Field, *Discovering Statistics Using IBM SPSS Statistics*, 5th ed., SAGE Publications Ltd, London, UK, 2017, ISBN: 9781526440310.
- [51] H. Wickham, *ggplot2: Elegant Graphics for Data Analysis*, New York: Springer; 2016, ISBN: 9783319242750
- [52] J. N. Cerasoni, F. do Nascimento Rodrigues, Y. Tang, E. Y. Hallett, Do-it-yourself digital archaeology: Introduction and practical applications of photography and photogrammetry for the 2D and 3D representation of small objects and artefacts, *PLoS ONE* 17(4) (2022), Art. no. e0267168  
DOI: [10.1371/journal.pone.0267168](https://doi.org/10.1371/journal.pone.0267168)
- [53] S. Porter, T. Rouseel, M. Soressi, A simple photogrammetry rig for the reliable creation of 3D artefact models in the field: Lithic examples from the early upper Paleolithic sequence of Les Cottés (France), *Advances in Archaeological Practice* 4(1) (2016), pp. 71–86.  
DOI: [10.7183/2326-3768.4.1.71](https://doi.org/10.7183/2326-3768.4.1.71)
- [54] D. Göldner, F.A. Karakostis, A. Falcucci, Practical and technical aspects for the 3D scanning of lithic artefacts using micro-computed tomography techniques and laser light scanners for subsequent geometric morphometric analysis. Introducing the StyroStone protocol, *PLoS ONE*, (2022), 17(4): e0267163, 12 pp.  
DOI: [10.1371/journal.pone.0267163](https://doi.org/10.1371/journal.pone.0267163)