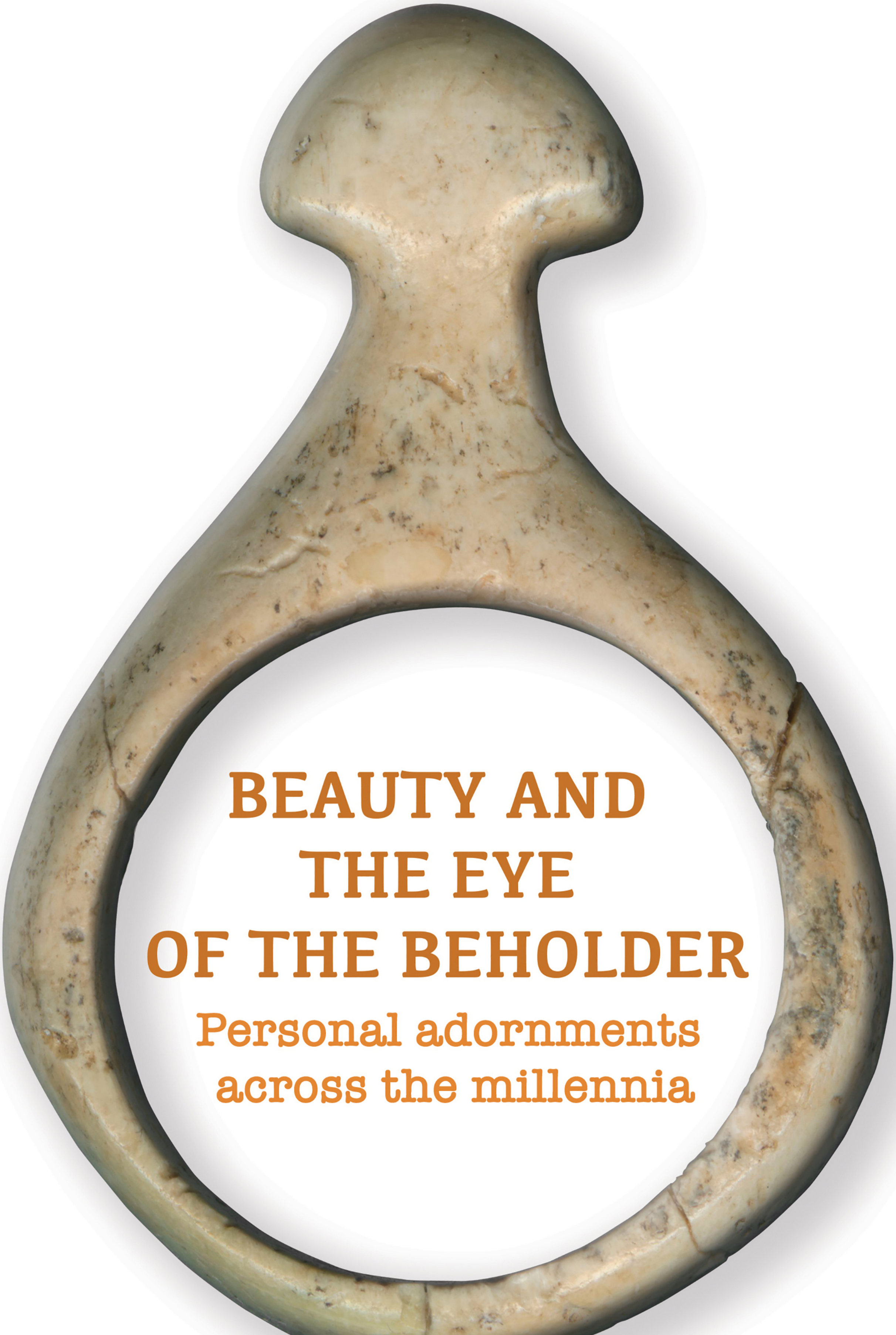

BEAUTY AND THE EYE OF THE BEHOLDER

Personal adornments across the millennia

Edited by Monica Mărgărit & Adina Boroneanț

CETATEA DE SCAUN

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Photo cover: Bone piece with a ringlike morphology from the necropolis of Sultana-*Valea Orbului* (Romania) and *Spondylus* beads from the necropolis of Urziceni-*Vamă* (Romania) (photos: Monica Mărgărit)

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FOREWORD

The message of personal adornments is not an easy one to decipher. Nevertheless, they provide an insight to the many aspects (social, spiritual, economic, etc.) of human behaviour, personal expression, relationships and communication. Understanding the complicated social and technical aspects of adornments generally require a broad spectrum of technical and methodological approaches as well as a good knowledge of the state of research and numerous local case-studies.

Beyond the aesthetic impact, at times secondary in traditional societies, personal adornments represents a language in itself, a complex communication system, conveying clear messages on ethnic, gender and age class affiliation. They are associated to certain rituals (e.g. passage or marital), they can be amulets or talismans and they can act as currency or as symbols of the ritualistic trade (e.g. Sciama 1998; Trubitt 2003; Vanhaeren 2005, etc.).

Moreover, their manufacture can be related to complex territorial and economic organization helping to identify in certain cases crafts and specialized workshops, circulation paths of raw materials and the existing systems for inter-community exchange (e.g. Newell *et al*. 1990; Vanhaeren and d'Erico 2006; Rigaud *et al*. 2015). Further information can be extracted from their presence in funerary contexts, revealing whether they were exclusively created for the afterlife or had been part of the every-day life of the respective individual/community.

There is already an impressive literature dedicated to personal adornments, which analyses the most diverse aspects: from their possible social-cultural functions to the means of obtaining the raw materials, the techniques used for their transformation, the ways they were used/repaired and their discard (e.g. Bar-Yosef Meyer *et al*. (eds.) 2017; Bar-Yosef Mayer and Bosch (eds.) 2019; Baysal 2019; Ifantidis 2019; Mărgărit 2019; to exemplify only with the latest publications). Nevertheless, as this volume also shows, the subject is a vast one and there is continuous need for further exploration.

***

The International Colloquium: “Beauty and the eye of the beholder: personal adornments across the millennia” took place at Valahia University, Târgoviște, Romania, between 12 and 14 September 2019. Bearing in mind the complexity of the subject, the participants were invited to discuss a variety of topics, expressing the views of various “beholders” both in the past and at the present moment: their meaning/symbolism within the prehistoric/historical societies (e.g. cultural tradition, social and spiritual organization and exchange systems), raw materials (identification of sources and acquisition), various methodologies of study (technological and usewear analyses, microscopy, SEM+EDS analysis, FTIR and RAMAN spectroscopy, etc.) and experimental approaches (creating experimental reference collections), etc.

At the end of the colloquium, following the discussions with our colleagues, it was decided to gather all presentations in a volume while also inviting other contributions dedicated to this topic, in an attempt to capture a broader spatial and temporal image.

The result is the present volume comprising 26 studies organized in three major sections related to regional studies on adornments, and their use and presence in everyday life and afterlife. Within one section, papers were organized in chronological order. The papers in the volume cover geographically the whole of Europe and Anatolia: from Spain to Russia and from Latvia to Turkey; it spans chronologically many millennia, from the Middle Palaeolithic to the Iron Age (2nd – 4th centuries AD).

The volume opens with ten regional studies offering not only comprehensive syntheses of various chronological horizons (Palaeolithic - Daniella E. Bar-Yosef Mayer, Neolithic/Chalcolithic - Emma L. Baysal; Fotis Ifantidis; Selena Vitezović and Dragana Antonović; Sanda Băcueț Crișan and Ancuța Bobînă; Andreea Vornicu-Țerna and Stansislav Țerna; Roberto Micheli) but also new data on the acquisition and working of various raw materials or specific types of adornments (*Columbella rustica* shells - Emanuela Cristiani, Andrea Zupancich and Barbara Cvitkusić; wild boar tusk - Ekaterina Kashina and Aija Macāne; canid tooth pendants - Petar Zidarov). The unbreakable link between adornments of the everyday life and those of the afterlife it is also highlighted in some of the contributions.

The following section - *Adornments in settlement archaeology* - includes nine studies, covering the archaeological evidence from specific settlement sites. Many studies focused on the adornments' iconographic designs, meaning, and exchange but also on raw materials, technologies of production and systems of attachment. Chronology-wise, this section brings together the most varied range of ornaments, raw materials and processing techniques from sites in Spain (Esteban Álvarez-Fernández), Turkey (Sera Yelözer and Rozalia Christidou), Greece (Catherine Perlès and Patrick Pion; Christoforos Arampatzis) and Romania (Adina Boroneanț and Pavel Mirea; Ioan Alexandru Bărbat, Monica Mărgărit and Marius Gheorghe Barbu; Monica Mărgărit, Mihai Gligor, Valentin Radu and Alina Bințințan; Gheorghe Lazarovici and Cornelia-Magda Lazarovici; Vasile Diaconu).

The last section - *Adornments of the afterlife* - focuses on ornaments identified in various funerary contexts allowing for a more detailed biography of ornaments through mostly use- and micro-wear studies, in order to reconstruct their production sequence and use life. Raw material availability and their properties, as well as contexts of deposition are also taken into account. In the seven studies of the section, different funerary contexts from Latvia (Lars Larsson), Ukraine (Nataliia Mykhailova), Hungary (Zsuzsanna Tóth) and Romania (Monica Mărgărit, Cristian Virag and Alexandra Georgiana Diaconu; Vlad-Ștefan Cărăbiși, Anca-Diana Popescu, Marta Petruneac, Marin Focșăneanu, Daniela Cristea-Stan and Florin Constantin; Dragoș Măndescu; Lavinia Grumeza) are discussed.

We would like to thank to all contributors who responded to our call and helped us complete this volume in less than a year. Each paper was submitted to external reviews. Therefore, we would like to also thank our colleagues who accepted to anonymously review the contributions, thus improved the overall content of the volume.

The Editors

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COMBINING MICROSCOPIC ANALYSIS AND GIS TO ANALYSE EXPERIMENTAL PERFORATIONS ON *COLUMBELLA RUSTICA* SHELLS

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Abstract: This paper focuses on *Columbella rustica*, a marine gastropod species widely attested within the Upper Palaeolithic and Mesolithic Europe ornamental repertoire. We attempt to characterize four different techniques of perforation on *Columbella rustica* shells through the application of qualitative and quantitative approaches. Our goal is to record diagnostic technological traces associated with each technique and, finally, build a comparative reference collection to be used for archaeological interpretations. Furthermore, we investigate the morphology of the holes created by each of the tested techniques, along with the distribution of technological traces formed around the shell perforation rim, using GIS. Through the combination of qualitative and quantitative approaches we test the potential of a synergetic analysis for reconstructing ancient ornamental biographies and technological traditions.

Keyword: microscopic analysis, GIS, experimental perforations, *Columbella rustica* shells.

Introduction

Ornaments have always had a privileged place in the study of the origins of culture and development of symbolic thinking due to their widely recognized role in the construction development of personhood, identity, and social networks in human societies. In Europe, the use of ornaments from marine shells is attested already by ca. 115ka ago at Cueva de los Aviones, a Neandertal-associated Middle Paleolithic site in southeast Spain (Hoffmann *et al*. 2018). However, it is only from ca. 40kya that marine and freshwater gastropods and bivalves, as well as a variety of animal teeth, bones, ivory and stone, become part of the Palaeolithic hunter-gatherer symbolic vocabulary, and even-regional patterns in their use have been identified, some of which lasted for millennia (Álvarez Fernández 2006; Vanhaeren and d'Errico 2006; White, 2007).

Within the early prehistoric repertoire of body adornments, shells of marine and freshwater gastropods often required only a slight modification to be transformed into ornaments, i.e. the creation of the hole. Different techniques are documented for creating perforations on such shells, the identification of which provided insights for reconstructing past technological choices and traditions (Vanhaeren and d'Errico 2001; Chauviere 2002; Álvarez Fernández 2006; Benghiat *et al*. 2009; Rodríguez-Hidalgo *et al*. 2010; Cristiani 2012; Stiner *et al*. 2013; Alarashi 2014; Tátá *et al.* 2014; André and Bicho 2016; d'Errico and Backwell 2016; Mărgărit 2016;

Mărgărit *et al.* 2018). Several authors have undertaken experimental analysis to evaluate the anthropic nature of perforations on archaeological marine gastropods shells (Cabral and Monteiro-Rodrigues 2015) as well as to characterize specific perforation techniques (Vanhaeren and d'Errico 2001; Chauviere 2002; Álvarez Fernández 2006; Benghiat *et al.* 2009; Rodríguez-Hidalgo *et al.* 2010; Cristiani 2012; Stiner *et al.* 2013; Alarashi 2014; Tátá *et al.* 2014; André and Bicho 2016; d'Errico and Backwell 2016; Mărgărit 2016; Mărgărit *et al.* 2018). To date, the technological approach applied to study experimental and archaeological shell ornaments has mainly been focused on the description of technological traces based on the qualitative comparison with experimental replicas.

Technological traces, spatial distribution and hole morphologies are essential to understand the anthropic nature of the perforation and differentiate between piercing techniques. These variables can be quantitively analyzed using Geographical Information System (GIS). GIS has been widely used in functional studies, in particular in the analysis of edge damage formation on knapped stone tools (Schoville 2010; Schoville and Brown 2010; Schoville *et al.* 2016) and on macro tools (Benito-Calvo *et al.* 2015; Caricola *et al.* 2018), and more recently to analyze residue spatial distribution (Mercader *et al.* 2018; Zupancich *et al.* 2019). To date, there has been a minimal application of quantitative methods in the analysis of perforated shells, although their interpretative potential has been demonstrated in the analysis of spatial distribution patterns of the wear on shell ornaments from South African Middle Stone Age contexts (Hatton *et al.* 2020).

This paper focuses on *Columbella rustica*, a marine gastropod species widely attested within the Upper Palaeolithic and Mesolithic European ornamental repertoire. We attempt to characterize four different techniques of perforation on *Columbella rustica* shells through the application of qualitative and quantitative approaches. We analyze experimental holes at low magnifications in order to record specific technological traces associated with each technique and, finally, build a comparative reference collection to be used for archaeological interpretations. Furthermore, we investigate the morphology of the holes created by each of the tested techniques, along with the distribution of the technological traces formed around the shell perforation rim, using GIS. The synergetic combination of the qualitative microscopic observations and the quantitative dataset obtained through GIS analysis allowed us to assess diagnostic technological traces for each technique, specific features in the hole morphology (e.g. dimensions, orientation) and/or in the distribution of the technological traces according to different perforation techniques as well as to achieve information concerning the morphology of the tool used to produce a specific hole.

Materials and methods

Experimental activity and the analysis of technological traces

A total of 40 *Columbella rustica* shells have been used (Fig. 1). Experimental shells were divided into four groups and perforated testing direct and indirect percussion techniques documented in the archaeological record (Álvarez Fernández 2006; Benghiat *et al.* 2009; Rodríguez-Hidalgo *et al.* 2010; Cristiani 2012; Mărgărit 2016; Mărgărit *et al.* 2018). In particular, holes on *Columbella* shells have been produced on the main body whorl through using: (a) direct percussion using a pebble (n. 10) (Fig. 2a); (b) direct percussion using a flint core (n. 10) (Fig. 2b); (c) indirect percussion using a flint flake and a pebble (n. 10) (Fig.2 c); (d) indirect percussion using a retouched flint point and a pebble (n. 10) (Fig. 2d). The following criteria were described and recorded on the experimental *Columbella* shells: perforation shape, section morphology of the walls, percussion flake, micro-flaking, compressions, crushing and notching marks, striations, and cracks. In particular, the outline of the perforation (circular, oval, sub-regular, and irregular), the section morphology of the perforation walls (straight, internally bevelled or jagged), the presence/absence of the percussion flake, the position (internal or external) and the invasiveness of the micro-flaking, the presence/absence and the organization (isolated or bands) of striations, the invasiveness of compressions marks as well as the presence/absence of crushing and notching were recorded together with the presence/absence of cracks starting from the perforation rim for each perforated shell.

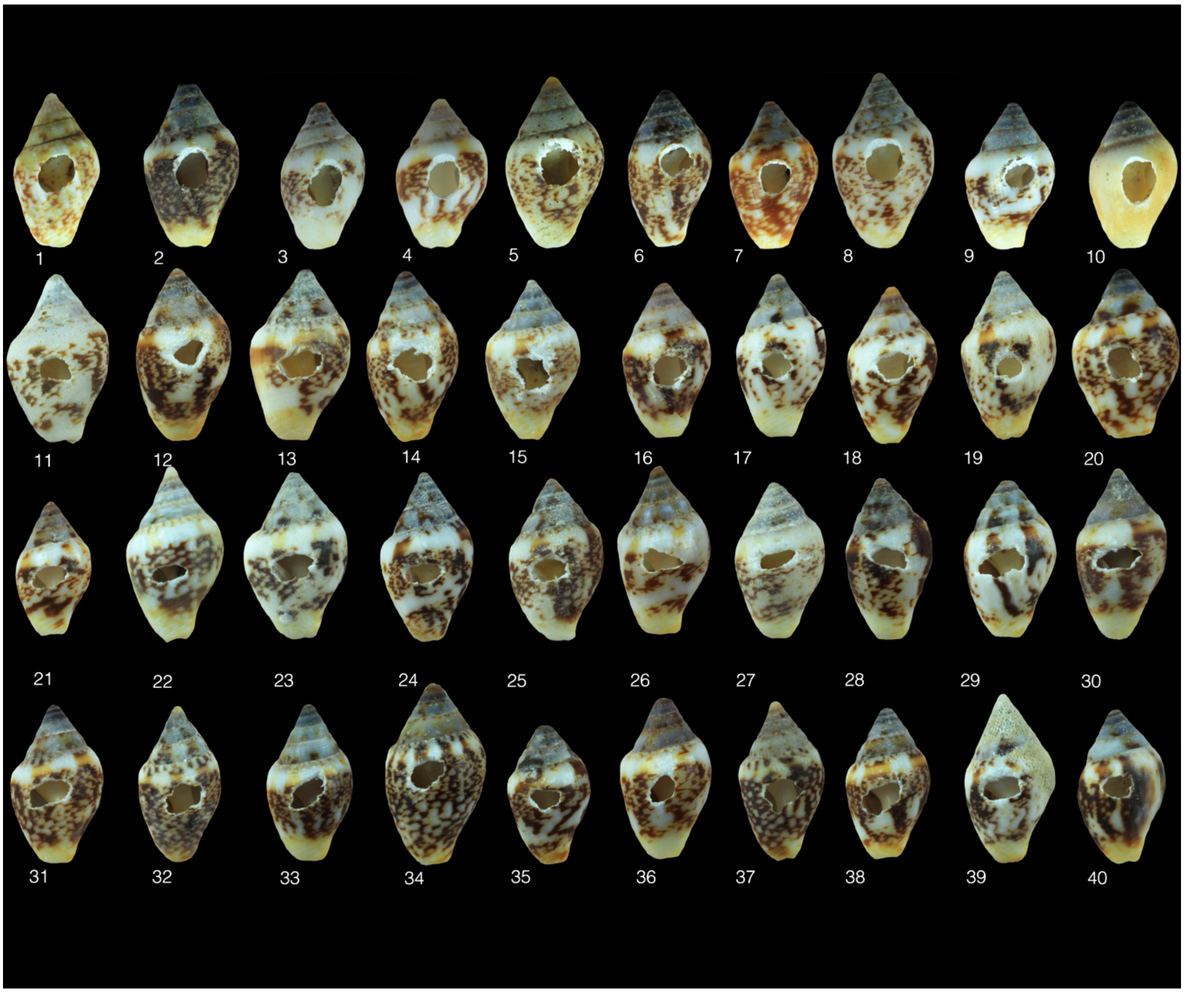

Figure 1. The sample of modern *Columbella rustica* on which different perforation techniques have been tested: 1-10) Direct percussion with pebble; 11-20) Direct percussion with flint core; 21-30) Indirect percussion with flake edge and pebble; 31-40) Indirect percussion with retouched point and pebble.

Each experimental shell was analyzed at low magnification using a Zeiss AxioZoom Digital Stereomicroscope with magnifications ranging from 10x to 168x and photographed at 20x using a Zeiss Axiocam 305 color camera. Diagnostic technological traces have been identified and described on the basis of widely published criteria (Vanhaeren and d'Errico 2001; Chauviere 2002; Álvarez Fernández 2006; Benghiat *et al.* 2009; Rodríguez-Hidalgo *et al.* 2010; Cristiani 2012; Stiner *et al.* 2013; Alarashi 2014; Tátá *et al.* 2014; Falci 2015; André and Bicho 2016; d'Errico and Backwell 2016; Mărgărit 2016; Mărgărit *et al.* 2018).

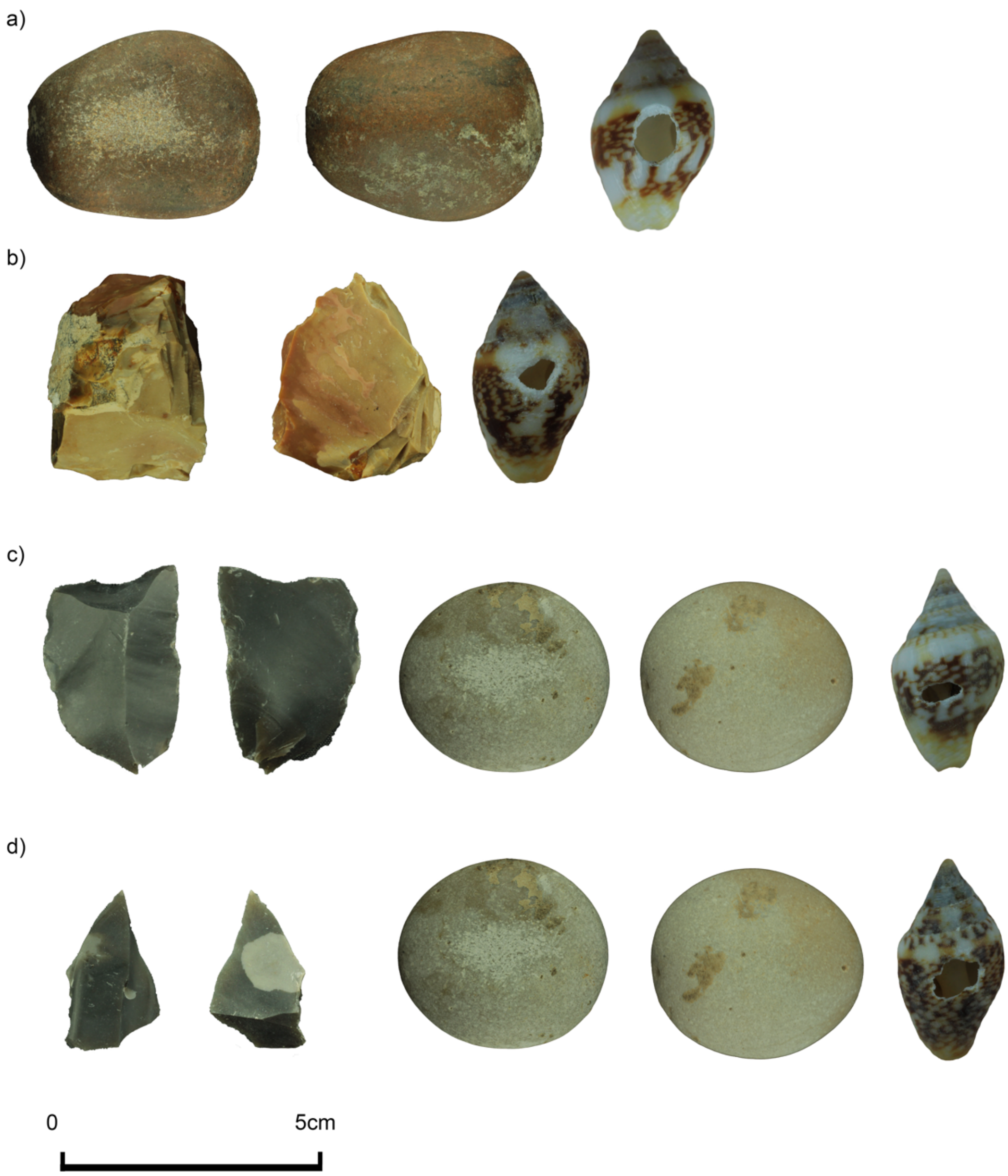

Figure 2. The tool-kit utilised for perforating *Columbella rustica* shells. a) pebble and (b) flint core used in direct percussion; c) flake; d) retouched point and pebble used in indirect percussion.

Morphometric and Spatial Analyses

The morphometric characteristic of the perforation holes obtained through the tested perforation techniques has been analyzed using GIS. Each experimental replica was photographed using a Canon EOS100D equipped with a 50 mm fixed macro lens and graph paper was used as a background. Once imported in QGIS (v.3.10) the images were georeferenced, and each perforation hole was digitized as a vector shapefile from which morphometric features were calculated. These included the dimensions of the perforation holes (maximum height, maximum width, area and perimeter), their orientation and circularity. As a measure commonly used in image analysis, circularity was calculated in order to compare the degree of roundness of the perforation holes associated to each of the performed techniques.

GIS software was used in the analysis of technological traces distribution over the perforation holes. For each technique, a convex hull resulting from the mean shape of each perforation hole was used, and the hole was divided into four (4) quarters, namely Q1,Q2,Q3 and Q4, which were rendered in GIS as vectorized shapefiles. Only the most represented type of modification was considered for each perforation technique, and random points were automatically positioned into the respective quarter. For each of the tested perforation techniques, the type and location of the identified traces were recorded, and random points were generated in the respective slice accordingly. Spatial patterns of the wear associated with different perforation techniques were analyzed using heatmaps. This permitted to visualize the distribution of specific types of wear associated with each of the adopted perforation techniques and gestures applied.

Results

Technological traces

Direct percussion using a pebble. Such technique produces regular holes with a circular outline (Fig. 3). The holes are characterized by the presence of invasive compression marks, produced by the regular outline of the pebble used for the experimental activity and mostly localized on Q1, as well as a straight section of the perforation walls. Occasionally, percussion flakes are recorded in Q1 and Q3 while isolated cracks from the perforation rim towards the body whorl are recorded on Q3.

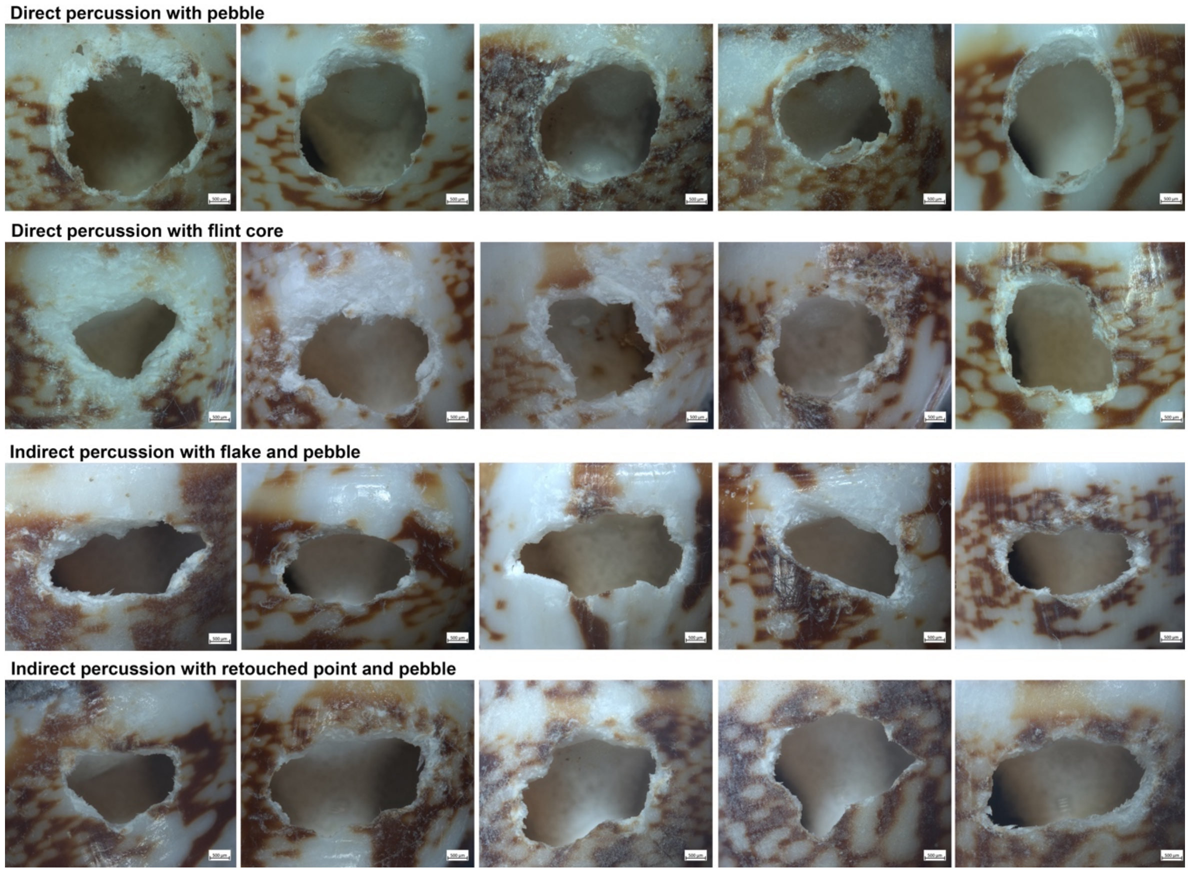

Figure 3. Experimental perforations on *Columbella rustica*. All pictures are taken at 20x of magnification.

Direct percussion using a flint core. Overall, such technique produces holes with a sub-regular outline (Fig. 3). The holes are characterized by invasive crushing and notching marks, produced by the irregularities of the flint core used for the experimental activity, mostly localized across Q1 and Q2. Surface striations localized in Q3 are also identified together with isolated cracks in Q3 and Q4.

Indirect percussion using a flint flake and a pebble. Such technique produces transversally elongated oval holes with an irregular outline (Fig. 3). The section of the perforation walls is generally straight. Invasive crushing and notching marks are frequent in Q1 while isolated compressions and cracks are documented in Q3. Numerous overlapping bundles of striations are identified in Q2, Q3 and Q4.

Indirect percussion using a flint retouched point and a pebble. Such technique produces holes with both oval and irregular outline (Fig. 3). Compression marks are localized in all the quarters as well as overlapping striations, which are well documented in Q1 and Q3. The presence of percussion flakes are recorded in Q2 and Q3. The section of the perforation walls is generally straight.

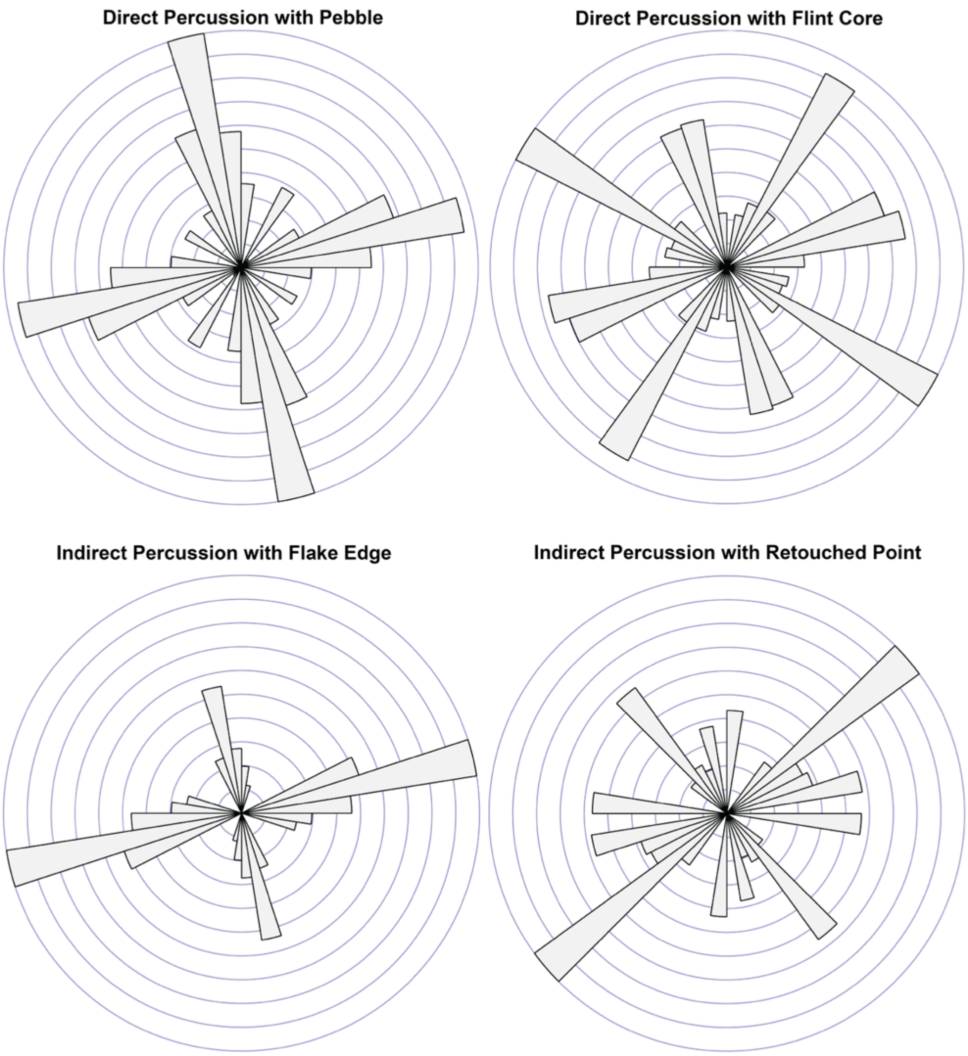

Figure 4. Rose diagrams showing the orientation patterns of the experimental perforations.

Perforation holes morphometric and spatial analysis

The holes generated by direct percussion with a pebble have a regular shape as indicated by their circularity value (mean 0.87 ad.). The mean area of the hole is 7.8 mm^2, while the maximum height and width recorded are 3.88 mm and 3.71 mm, respectively. The perforation holes exhibit both horizontal and vertical orientation, with the latter resulting to be more frequent (Fig. 4). The most represented modifications are compression marks and straight section of walls. These are mostly localized in Q2 of the perforation hole, with lower concentration of technological traces in Q1 and Q4 (Fig. 5).

Perforation holes produced by direct percussion using a flint core are characterized by a mean circularity value of 0.78 ad. The mean area of the hole is 4.68 mm^2, with a maximum recorded height of 3.71 mm and a maximum width of 3.15 mm. The holes' orientation is random, with no observed preferential horizontal or vertical pattern (Fig. 4). Invasive crushing and notching is the most represented type of modification, along with jagged sections and surface striations. Invasive crushing and notching is particularly evident in Q1, while in Q2 and Q4, it appears in combination with surface striations and jagged sections (Fig. 5).

The perforation holes generated by indirect percussion using the edge of a flint flake exhibit a mean circularity of 0.72 ad. The dimension of the holes is relatively small (mean area 4.3 mm^2), with a maximum recorded height and width of 3.95 mm and 2.6 2mm. The perforation holes exhibit a distinct horizontal orientation pattern (Fig. 4). Surface striations and compression marks are the most represented technological modifications. Surface striations are localized mostly in Q3, while compression marks are visible mostly in Q4. Traces are sporadic in Q2 and are nearly absent in Q1 (Fig. 5).

Holes generated through indirect percussion using a retouched flint point and a pebble return a mean circularity of 0.77 ad. Their average area is of 5.17 mm^2, and their maximum height and width are of 3.93 mm and 2.77 mm respectively. Their orientation pattern is mostly diagonal across the shell surface (Fig. 4). Compression marks and straight section of walls are the most represented traces. These are visible over all the four quarters of the hole, with higher concentrations over Q1 and Q2. (Fig. 6 and 7).

Discussion and Conclusions

The aim of this paper is to assess whether it is possible to associate specific manufacturing traces and quantitative patterns in the technological modifications to different techniques of perforation of *Columbella rustica* shells. Specific technological criteria have been selected for describing the traces identified and, for some, specific variables have been recorded, such as position, abundancy, overlapping, invasiveness (e.g. position of micro-flaking, the morphology of the section of the walls, abundancy and characteristics of striations, presence/absence of compression, crushing and notching marks etc.). From a qualitative perspective, our analysis indicates that the different techniques applied in the experimental protocol can be distinguished on a microscopic level by analyzing the recurrence of diagnostic technological traces and their presence/ absence/position on the hole. In particular, direct percussion with a pebble seems to be characterized by regular round holes mainly characterized by invasive compression marks on the upper quarters as well as a straight section of the perforation walls (Fig. 3). Direct percussion with a flint core is also specifically characterized by invasive crushing and notching marks as well as by jagged section of the perforation walls (Fig. 3). Indirect percussion with a flint flake edge resulted in developed patterns of surface striations, often located in the lower quadrants and possibly due to the movement of the flint/point and edge across the shell body whorl. This technique is also characterized by the presence of crushing as well as compression marks (Fig. 3). Striations and compression marks also characterized the indirect percussion with a pointed flint tool, although this technique also seems to leave a jagged section of the wall (Fig. 3).

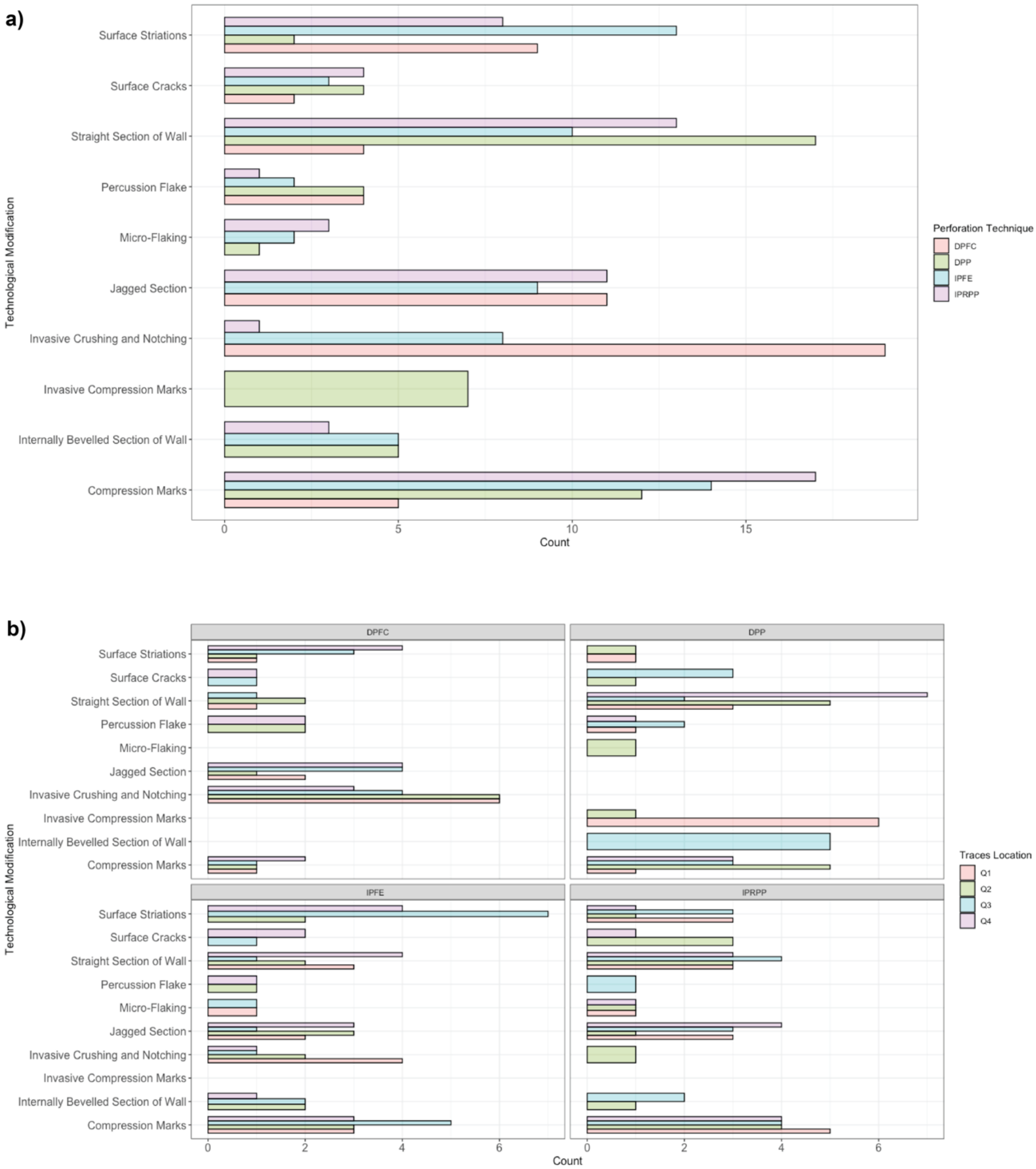

Figure 5. Bar plots of the observed technological modification. a) traces observed for each perforation techniques; b) traces observed for each perforation technique according to their location on the hole. DPP= direct percussion with pebble; DPFC= direct percussion with flint core; IPFE= indirect percussion with flake edge; IPRPP = indirect percussion with retouched point and pebble.

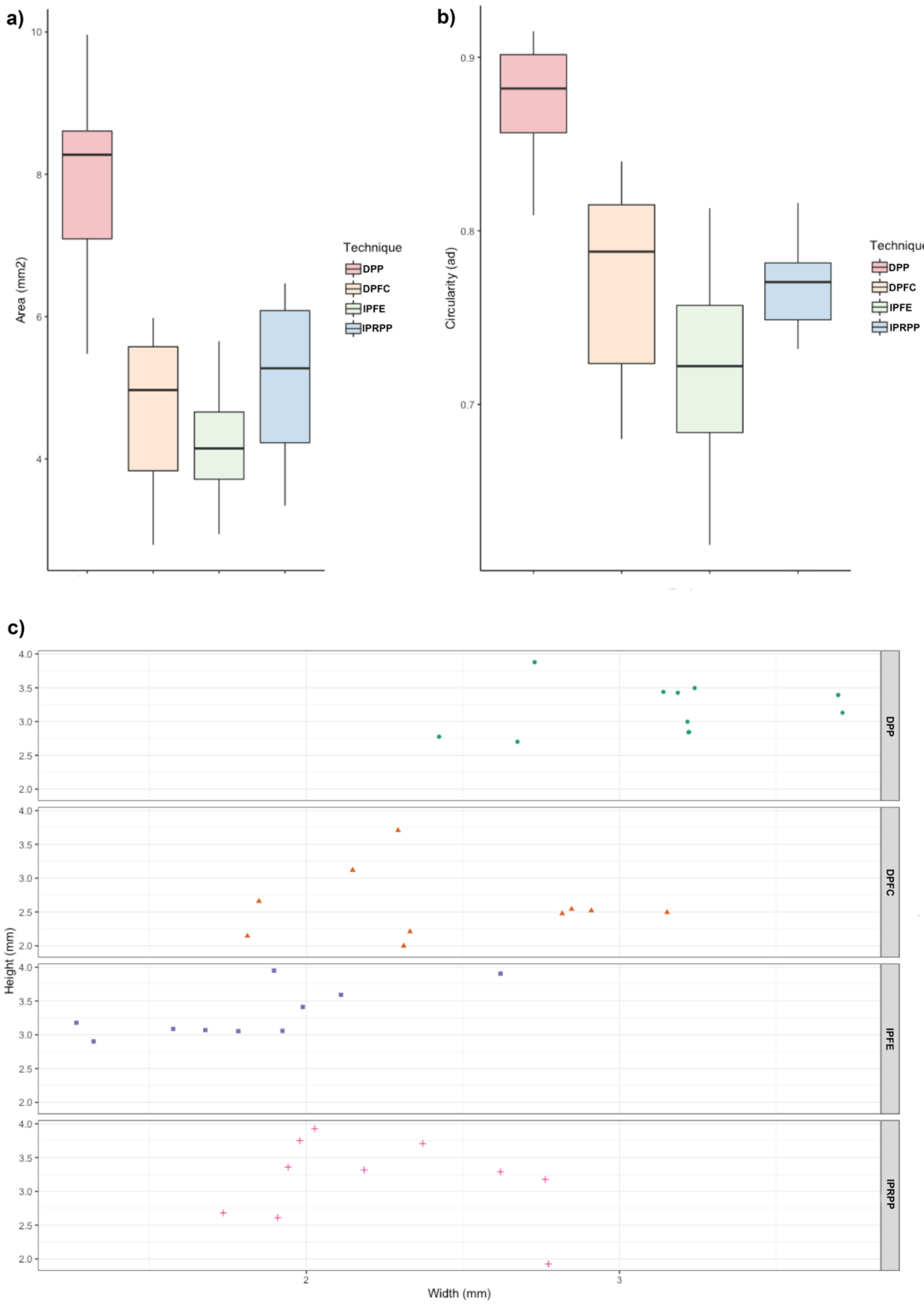

Figure 6. Morphometric characteristics of the experimental perforations. A) Boxplot of the area of the perforations; b) boxplot of the circularity of the perforations; c) scatterplot of the width and height of the perforations. DPP= direct percussion with pebble; DPFC= direct percussion with flint core; IPFE= indirect percussion with flake edge; IPRPP = indirect percussion with retouched point and pebble.

In regard to the morphometrics of the perforation holes, several distinct features have been associated to each of the performed techniques (Fig. 6). In regards to dimensions, the largest holes are created through direct percussion with a pebble (mean area 7.8 mm^2; mean height 3.17 mm; mean width 3.13 mm). The smaller perforation holes are associated to indirect percussion with a flint flake (mean area 4.3 mm^2; mean height 3.32 mm; mean width 1.82 mm). Medium-sized holes are associated to direct percussion with a flint core (mean area 4.68 mm^2; mean height 2.59 mm; mean width 2.45 mm) and to indirect percussion with a flint point and a pebble (mean area 5.17 mm^2; mean height 3.17 mm; mean width 2.23 mm). Differences are noticed also in the roundness of the outline of the holes associate to each technique. The computed circularity values indicate that more regular holes are created through direct percussion using a cobble (mean 0.87 ad), while more irregular ones are associated to the perforation through indirect percussion using a flint flake edge (mean 0.72 ad.). Direct percussion using a flint core and indirect percussion using a flint point and pebble returned very similar circularity value, 0.78 ad. and 0.77 ad. respectively.

Table 1. Summary statistics of the morphometric features characterizing the experimental perforations.

Direct Percussion with Pebble	**Mean**	**Std.Dev**	**Min**	**Median**	**Max**
Area (mm2)	7.80	1.38	5.48	8.27	9.96
Perimeter (mm)	10.58	1.03	8.89	10.85	11.86
Height (mm)	3.17	0.38	2.70	3.13	3.88
Width (mm)	3.13	0.40	2.42	3.22	3.71
Angle (°)	72.57	19.51	27.53	76.04	93.89
Circularity (ad)	0.87	0.05	0.78	0.88	0.92
Direct Percussion with Flint Core	**Mean**	**Std.Dev**	**Min**	**Median**	**Max**
Area (mm2)	6.03	4.67	2.79	4.97	18.93
Perimeter (mm)	9.42	2.77	6.56	9.09	16.40
Height (mm)	2.83	0.90	2.00	2.52	4.95
Width (mm)	2.65	0.92	1.81	2.32	4.95
Angle (°)	77.95	32.53	28.80	75.60	131.05
Circularity (ad)	0.78	0.07	0.68	0.79	0.88
Indirect Percussion with Flake Edge	**Mean**	**Std.Dev**	**Min**	**Median**	**Max**
Area (mm2)	4.30	1.06	2.94	4.15	6.30
Perimeter (mm)	8.62	1.14	7.11	8.22	10.70
Height (mm)	3.32	0.38	2.90	3.13	3.95
Width (mm)	1.82	0.40	1.27	1.84	2.62
Angle (°)	81.34	9.88	70.94	78.70	102.92
Circularity (ad)	0.72	0.06	0.62	0.72	0.81
Indirect Percussion with Retouched Point and Pebble	**Mean**	**Std.Dev**	**Min**	**Median**	**Max**
Area (mm2)	5.17	1.13	3.34	5.27	6.47
Perimeter (mm)	9.13	1.17	7.41	9.31	10.37
Height (mm)	3.17	0.61	1.93	3.30	3.93
Width (mm)	2.23	0.38	1.74	2.11	2.77
Circularity (ad)	0.77	0.03	0.73	0.77	0.84
Angle (°)	75.89	25.24	47.00	72.84	128.93

Differences are also recorded concerning the orientation of the perforation holes compared to the shell axis. Both parallel and perpendicular orientations are recorded for the holes associated with direct percussion with a pebble, while a perpendicular orientation characterizes the ones obtained through indirect percussion with a flint flake and pebble. A diagonal orientation is instead typical of the holes produced through indirect percussion using a flint point and pebble, while direct percussion with a flint core results in more randomly oriented perforations holes.

The analysis of the spatial distribution of technological modifications allowed to identify some differences in the localization of the most diagnostic traces tested for perforating *Columbella rustica* shells (Fig. 7). Holes produced by direct percussion using a flint pebble exhibit clusters of diagnostic traces in Q2 where concentrations of compression marks are documented and the section morphology of the walls is straight. A similar pattern, with the higher concentration of diagnostic traces localized in a specific quarter, is observed in holes produced by indirect percussion using a flint edge and pebble, where surface striations appear localized mostly in Q3. Conversely, in the case of direct percussion using a flint core and indirect percussion using a flint point and pebble, diagnostic technological traces appear more evenly distributed around the perforations. It is worthy of observation that in the case of direct percussion with a flint core, invasive crushing and notching marks are mainly located between Q1 and Q2.

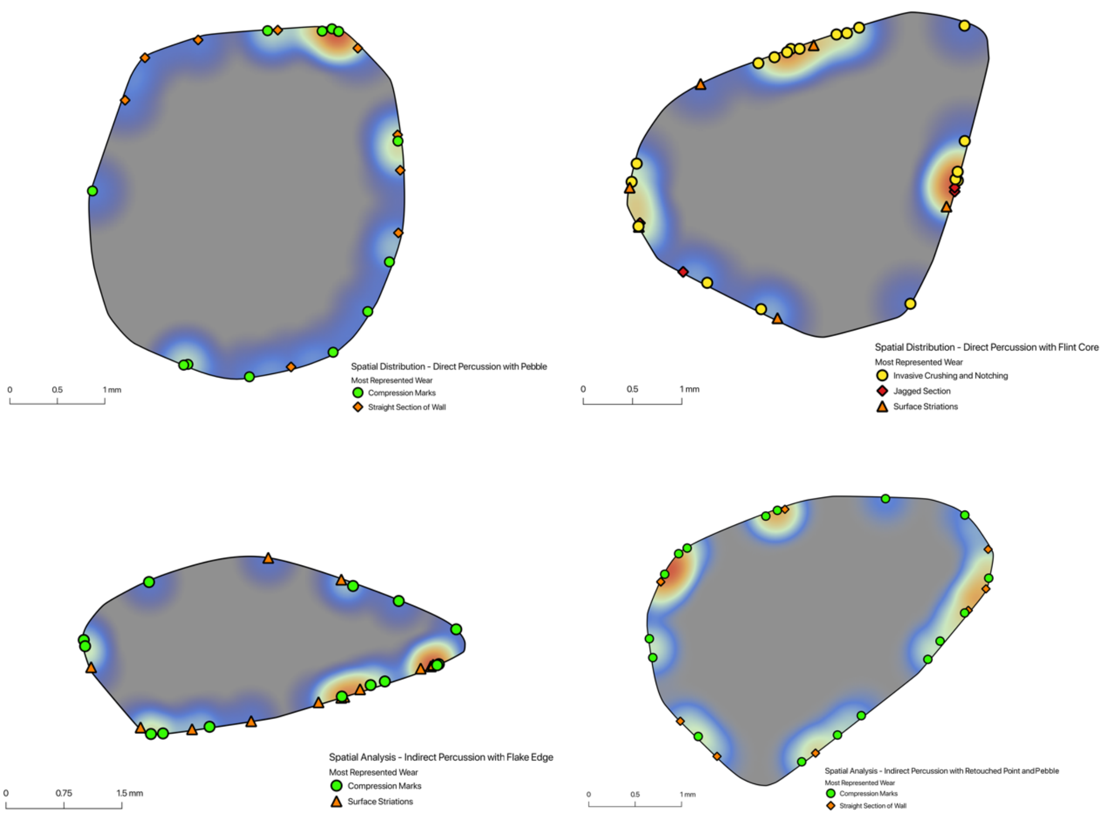

Figure 7. Heatmaps showing the distribution of technological traces on the experimental perforations.

Quantitative data also suggest that differences observed in the distribution of the technological traces around the perforation hole could be strictly related to the morphological characteristics of the tool used to produce the hole. Indeed, the rounded morphology of the cobble used in direct percussion with a pebble involves the contact between the tool and the entire hole, leading to a homogeneous distribution of the modifications, with just a minimum concentration of traces in Q2, possibly coinciding with the point of maximum exerted force.

In the case of direct percussion with a flint core, the presence of traces clusters in three quarters. This can be linked to the dihedral morphology of the portion of the core used to produce the hole, with the traces concentrations coinciding with the core's sharp angles.

In the case of indirect percussion with a flint flake edge, most of the technological modifications are concentrated in the three quarters (Q1, Q3 and Q4) coinciding with the extremities of the wide axe of the hole, possibly corresponding to the portions of the flake edge more in contact with the shell body whorl. Indirect percussion using a retouched flint point and a pebble instead result in a homogeneous distribution of technological modifications around the hole, similarly to the one characterizing just the holes produced through direct percussion with a pebble. The only difference is in the higher number of traces clusters, which are presumably related to the topography of the pointed tool's surface in contact with the shell, richer in asperities (i.e. ridges) than the surface of the pebble.

In conclusions, our experimental work documented the potential of a combined qualitative and quantitative approach applied to the technological study of shell ornaments. We demonstrated how such an approach could provide relevant information concerning the specific techniques used for perforating *Columbella* shells through the identification of diagnostic technological marks. We tested the potential of GIS for providing quantitative data regarding the morphology of perforation holes associated to different techniques. Moreover, we underlined how, through the analysis of traces spatial distribution, it is possible to achieve information concerning the morphology of the tool used to produce a specific hole. Although this latter aspect needs to be further developed through new experiments and archaeological analyses, we believe that the preliminary results on *Columbella rustica* shells presented in this paper underline the interpretative potential of a combined qualitative and quantitative approach for reconstructing ancient ornamental biographies and technological traditions.

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