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Late Acheulian multiplicity in manufactured stone culture at the end of the Middle Pleistocene in Western Europe

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Abstract

In Prehistory, Paleolithic stone toolkits are allotted to distinct cultural phases, explained through a periodization that has been adopted as a strategic reference by specialists in lithic studies, based on: 1) the categorization of morpho-types observed in the assemblages; 2) the dominant manufacture technologies and 3) temporal categorizations based on geo-archeological data. Significant changes in toolkits are observed through time, signaling variations in extinct hominin behavioral configurations. They characterize the denominative classifications of the techno-complexes, presently defined under consensus. Applying the *Homogeneity, Variability, Diversity, Multiplicity* (HVDM) paradigm as a conceptual scheme for understanding the structural evolution of human technologies, we define the *Multiplicity* phase, exploring the techno-social consequences of changes materialized in the Late Acheulian of Western Europe, presaging the Middle Paleolithic world of the Neandertals and the arrival on the scene of our own species; *Homo sapiens*. During this period, in Western Europe, *Homo heidelbergensis* was undergoing biological transformations, which appear to have fused into a range of hominin forms, raising questions of intra-species contacts and cultural exchange on a backdrop of branching evolutionary configurations. Beyond handaxe production, this period is marked by significant social and behavioral revolutions: changes in landscape use, high population mobility and inter-connectivity, tool-type diversity, technological innovations, as well as the expansion of distinct hominin clades throughout the Old World. We examine the impulses for these changes, in particular, the prominent role played by the mastery of fire in revolutionizing human socialization processes.

Key words

Multiplicity; Late Acheulian; Stone tools; Cultural transmission; Hominin migrations; Fire making

Introduction

This paper presents the fourth and final phase of the "*Homogeneity, Variability, Diversity and Multiplicity* Model (HVDM model), a structural paradigm developed by Carbonell et al. (2009) as an alternative approach to understanding the evolution of human technologies throughout the Pleistocene and the development of distinct cultural units that appeared, muted and were diffused over vast geographical expanses through time. The model is already in use to illustrate how the analysis of stone tool assemblages can provide insights into the evolutionary systemic of human behaviors and the cognitive levels they reflect (Carbonell et al., 2016; Barsky et al., 2018, 2019). It is proposed as a deviation from the traditional classificatory constructs composing the foundations of typological analysis (Bordes, 1961) and as an alternative conceptual framework for understanding technological change observed in ancient lithic toolkits. Undeniably, seemingly ineluctable typological classificatory systems continue to permeate even the most progressive technological interpretations, in particular for the Middle and Upper Paleolithic records, which remain, nevertheless, deeply entrenched in such notions as relative tool-type frequencies and (even still) fossil directors (François Bordes: presence of particular tool types found in archeological horizons as signals for specific cultural entities and chronologies). Of course, the complementary vision provided by technological analysis, especially after the 1990s, engaging the milestone notion of *chaîne opératoire* (Eng. operative scheme or reduction sequence; Soressi & Geneste, 2011 and references) greatly enlarged the field of view provided by stone toolkits and the range of data potentially gleaned from them. Today, innovative new equipment and expertise contribute to establishing ever-more diverse areas of study, enhancing results obtained in the field of lithic analysis, for example: computerized spatial distribution and refitting studies or geometric morphometric investigations supported by 3D digital imagery of lithic tools (Lycett, 2009; Shott, 2014; García-Medrano et al 2018; Grosman et al., 2014; Herzlinger & Grosman, 2018; Titton et al., 2020), as well as progressing use-wear studies combining methodologies supported by high-powered microscopy and laser procedures for residue analysis (Ollé & Vergès, 2013; Caricola et al 2018; Borel et al 2014; Ollé et al 2016; Rots et al., 2016; Hayes et al 2018; Martín-Viveros & Ollé, 2020; Pedergnana et al., 2020), among others. Over time, all of this has allowed lithic studies to move beyond (but not abandon) its classical typological methodologies and to appreciate the pitfalls of applying unilateral approaches to something as complex as prehistoric cultural categorizations. It is now clear that, in order to distinguish boundaries (both cognitive and physical) that may actually exist and be defined and classified into distinct techno-complexes, we must not limit ourselves to pigeonholing lithic records by assembling together analogous morphologies of the different items they contain and imbuing them with chrono-cultural meaning.

By calling upon an array of different approaches, models and concepts in lithic studies (Clark, 1969; Isaac, 1972, 1977, 1983, 1986; Carbonell et al., 1992; 2009; Leakey, 1971; Shea, 2013; Boëda, 2013, etc.), we continue to move forward in our understanding of hominin lifeways and their evolution through time. Indeed, it seems that our own understanding does preclude some kind of categorization, in order to make sense of our observations, even while we struggle to avoid subjectivity. Culture evolves. We may all concede that, notwithstanding its diachronic character, human cultural evolution- interpreted from lithic toolkits in the Prehistoric register –occurs with a clearly recognizable and exponential tendency towards greater technical complexity and heterogeneity; since its perceptible emergence more than 3 Ma in Africa (Harmand et al., 2015) up to the present day. Toolmaking, while no longer considered the exclusive domain of the genus *Homo*, certainly seems have become a behavior that was more fully integrated into the lifeways of this genus (*H. habilis,* Villmoare et al., 2015) from around 2.6 Ma (Braun et al., 2019; Semaw et al., 2000). Considered thus as a behavioral trait, tool making might have been invented, re-invented, and transmitted by successive (and often coeval) hominin species along the evolutionary highway (de la Torre, 2019). In any case, the archeological record shows clearly that, through time, tool making became ever more massively adopted as a survival strategy by all succeeding representatives of the genus *Homo*, as species' members became increasingly dependent upon it through time. In its early stages, this process is understandable by the ostensible advantages that tools would have provided to hominins adopting this strategy for obtaining resources, enabling them to carve-out their own niche in relation to other large carnivores and in an ever-widening range of contexts. Furthermore, tool making enabled hominins to reduce the time spent in fulfilling the most basic of survival necessities; beginning with obtaining foodstuffs- in particular high protein-yielding meats and viscera. In the archeological record, this circumstance is reflected in the gradual increase in brain size, observed first and foremost in *Homo habilis*, relative to earlier hominin forms, and then in subsequent species of *Homo* as we move through time (Foley & Lee, 1991; Burini &

Leonard, 2018). Nowadays, relatively numerous sites attributed to the Oldowan techno-complex attest that the lithic assemblages are often found in association with large herbivore fossils bearing traces of percussion and cut marks made by stone tool-using hominins (Fejej Fj-1a, Barsky et al., 2011; FLK Zinj site, Bed I, Olduvai Gorge, Domínguez-Rodrigo, 2009; Domínguez-Rodrigo & Barba, 2006).

Demographic growth appears to have accelerated notably after around 1.5 Ma and onwards into the Acheulian, as attested by a steady proliferation in the number of sites, as well as in the density of archeological materials they comprise. After around 2 Ma, first *Homo* expanded into different territories/continents, suggesting enhanced survival capacities impacting on reproductive success (Tanzania, Leakey, 1973; Johanson et al., 1987; Tobias, 1991; South Africa, Ackermann et al., 2012; Kenya, Hill et al., 1992) that (we propose) reflects advantages reaped from their increasingly heavy investment in toolmaking and tool using. Looking to the larger picture of evolutionary tendencies, we find signs of augmented heterogeneity within the toolkits themselves- both on the technological and typological levels -from the so-called 'Developed Oldowan' (*ca*. 1.8 Ma, Leakey, 1971) or 'Late Acheulian' (de la Torre & Mora, 2014), marked by the recurrence of some distinctive artifact types (i.e. spheroids/sub-spheroids, retouched flakes, clearly configured macro-tools). During the Early Acheulian (generally attributed to *Homo ergaster* and *Homo erectus*), Large Flake-based toolkits containing a range of new and standardized tools (Large Flake Acheulian or LFA, Sharon, 2009) were made by sophisticated production technologies, (1.75 Ma, Lepre et al., 2011; Beyene et al., 2013), undoubtedly reflecting a broadening in range of activities. This underpins the fact that new technologies were being used to manufacture tools in accordance to specific mental templates with a clear orientation towards reproducing standardized morphologies (Sharon, 2011). It further signals the beginnings of new forms of socialization actually linked to the establishment of technical traditions for the production of recurrent tool forms. In addition, hominins began to make tools whose attributes were not necessarily linked to functional criteria (i.e. symmetrical bifaces).

We argue that it is precisely this aspect that triggered new notions of custom and tradition- the building blocks of culture -projecting toolmaking far beyond its initial role of simple survival strategy and into the realm of complex- and even symbolic -social practices. Among the most remarkable features occurring towards the end of the long evolutionary trajectory of the Acheulian (MIS 12), was the upsurge in the adaptive range of our genus (*Homo erectus* and derivative forms), whose technological prowess finally rendered it capable of thriving in ever more diverse ecosystems (Parfitt et al, 2010; Ashton & Lewis, 2012; Moncel et al., 2018). Migrating durably into new territories, Late Acheulian hominins expanded and solidified their cultural multiplicity into a highly significant, eco-social evolutionary trait of the human clade. In our analysis, it is important to consider the cognitive capacities of hominins that gave rise to the variability and diversity of tools found in archeological sites. From the biological point of view, the qualitative leap towards a vision of the properties of the raw material and the benefits related to its conscious alteration could be related to the diffusion within the hominin population of certain genetic changes. According to

Dennis et al. (2012), the SRGAP2 gene (silt-Robo Rho GTPase-activing protein 2) underwent a duplication about three to four million years ago, coinciding with the transition between *Australopithecus* and *Homo* and the appearance of the first tools. Of course, this hypothesis is speculative, because it is not possible to establish a direct relationship between one phenomenon and the other. Two new duplications of the gene would have occurred between 2.4 and 1.0 million years ago, probably coinciding with the expansion of the brain in the genus *Homo*. However, this gene does not seem to cause an increase in brain volume, but rather a greater connectivity between neurons (Charrier et al., 2012). Other researchers (Suzuki et al., 2018) have pointed out that the activation of the gene NOTCH2NL (located on chromosome 1) could be the mechanism that triggered the increase in brain size in the genus *Homo* about three million years ago. These are two examples of the attempt to link changes in the genome with increased cognitive abilities in hominins.

However, we are aware that it is not possible to establish a direct relationship between increased brain size and cultural complexity. Estimates of the encephalization quotient (Ruff et al., 1997), which relate brain mass and body mass, suggest a long period of stasis of the genus *Homo*, at least until the middle Middle Pleistocene. Rightmire (2004) goes even further and only finds a significant increase in the encephalization quotient with the appearance of the hominins that he includes in *Homo heidelbergensis*. In this biological context, there have been qualitative leaps in cultural complexity, without the concomitant leaps in the estimated encephalization quotient. In contrast, increases in the quotient of encephalization do not necessarily imply greater cultural complexity. It is therefore necessary to invoke other factors such as demographic increase and contact between populations or environmental pressure.

Having already applied the HVDM model to explore developmental trends in technology during the earliest periods of the Paleolithic: the emergence and development of the Oldowan (homogeneity and variability; Carbonell et al., 2009, 2018) and into the Developed Oldowan and Early Acheulian (diversity; Carbonell et al., 2016). This paper analyzes the underlying configurations, physical, technical and behavioral, that led to the spread of the Late Acheulian. We examine this cultural phenomenon in the Western European context after around 700 Ka (Sharon and Barsky, 2016), which corresponds with the beginning of the multiplicity phase in Europe (Caune de l'Arago, Notarchirico, La Noira), as discussed in this paper (Barsky, 2013a; Moncel et al., 2013, 2020). Preceding this date, there are few records of the Acheulian techno-complex in Europe (El Barranc de la Boella and US4 of Bois-de-Riquet; Vallverdú et al 2014; Bourguignon et al., 2016). However, after around 500 Ka, a comparatively wide spread (Roebroeks & van Kolfschoten, 1994) of the Late Acheulian (Sharon and Barsky, 2016) is attested.

- ***Definition of the Western European Late Acheulian***

In Western Europe, the Late Acheulian (LA) designates the final phase of the Acheulian techno-complex as it extends into the Middle Paleolithic, where it is found to coexist with the first Mousterian cultural *facies* from MIS 12 to MIS 9-8 (Leroi-Gourhan, 1988; Lumley, 2004; Méndez-Quintas et al., 2019; Key et al., 2021). In the hominin record, this chronological range corresponds with *H. heidelbergensis*, relatively widely represented throughout Western Europe (Rightmire, 1998) and with the appearance of the Neandertal lineage, whose divergence from the Denisovans is now believed to predate 430 Ka (Meyer et al., 2016) and whose lineage appears somehow linked with the European *Homo erectus* (Lumley, 2018). These Late Acheulian hominins are known to have lived in different types of habitat, including open-air (especially along watercourses), rock shelters and caves. Some sites contain depositional sequences with successive layers that reveal different types of hominin occupations (short, medium or long-term, seasonal, specialized or non-specific hunting, etc., often alternating sporadically with other large carnivores). This feature is indicative of the cyclical return of hominin groups to specific areas- sometimes over thousands of years (Barsky, 2013a; Ollé et al., 2013; Saladié et al., 2018; Moncel et al., 2020). LA sites are numerous and they often contain dense or even very dense concentrations of archeological materials. Finds include lithic tools and systematically butchered fauna with profiles typical of selective hunting practices and sometimes displaying markedly high indexes of anthropic intervention (Barsky, 2013a; Barsky et al., 2019; Rodríguez-Hidalgo et al., 2017). In addition, evidence for the use of fire is noted at some sites from 400-300 Ka (Terra Amata and Menez Dregan in France, Vértesszöllös in Hungary, Beeches Pit in England and Schöningen and Bilzingsleben in Germany, among others), but this behavior is not entirely ubiquitous until somewhat later (Roebroeks & Villa, 2011; Gowlett, 2016), from MIS 11 and especially after 9-8, when we begin to find truly structured hearth areas (Lumley, 2006; Fernández-Peris et al., 2012) and even some multilevel sites with mega-hearth structures (Cueva del Ángel, Barrosso-Ruiz et al., 2011).

Late Acheulian lithic assemblages may or may not contain handaxes (Notter, 2007; Barsky & Lumley, 2010; Lumley, 2015; Moncel et al., 2020) and, apart from sites in Spain and sparse appearances elsewhere in Western Europe, cleavers and LFA technologies are scarcely represented (Sharon, 2007; Sharon and Barsky, 2016; Santonja and Villa, 2006; Santonja et al., 2016; Santonja and Pérez-González, 2010;). Toolkits were made using a wide range of raw materials, coming sometimes from very distant sources and, in consistency with earlier Acheulian traditions; a clear correlation is established between the chosen raw materials and the tool categories (Barsky, 2013a). Core knapping systems are divers; oriented towards small to medium-sized flake production. Bifacial discoid (and related) core reduction strategies generally dominate and the cores can be very small-sized, especially compared to previous phases of the Acheulian. Meanwhile, a wide range of other core forms are present (as discussed below), ranging from cubic to globular and pyramidal, always reflecting systematization of the strategies regardless of the matrices' dimensions and raw materials used. Small retouched tools on flakes are very abundant and hardly distinguishable from Mousterian-type retouched toolkits: scrapers abound in proportions that are generally lesser than denticulate tools and pointed morphologies are very common. Some 'relic' tool types, such as *Limaces*, as well as Tayac and Quinson points may persist in some assemblages. Cobble tools are ubiquitous, following their own pathways to standardization, including pointed or convergent-edge chopper types, while some macro-tool 'types' such as spheroids, disappear or are not represented (Titton et al., 2020). Bone tools and bone retouchers are documented (Villa & d'Errico, 2001; Moigne et al., 2016), notably at some Late Acheulian sites in the Latium region of Italy (Fontana Ranuccio, Castel di Guido; Biddittu & Segre, 1982; Biddittu & Celletti, 2001; Boschian & Saccá, 2010). Comparative intra-site analyses between the toolkits in multi-stratigraphic contexts show subtle variations in the assemblages attributed to various causes: raw material variability, changing site-use contexts (hunting practices, hominin group size and constituent types) and climatic changes through time, that affected landscape and faunal resources (Barsky, 2013a; García-Medrano et al., 2015; Lombera-Hermida et al., 2020) Regional variations in these criteria have led prehistorians to recognize and define 'traditions' within the LA, thus linking them- for the first time -to specific territorial areas (Barsky et al., 2018; Grifoni & Tozzi, 2006).

In previous works, we apply the HVDM model to describe analogous evolutionary phenomenon observed in the Asian context in a similar timeframe (Barsky et al., 2018). The HVDM model serves to investigate the singularity of the human paradigm: techno-dependency– to construct a complementary vision that is useful to perceive how evolutionary change occurred through time in human techno-systems. In addition, this approach services our understanding of *why* culture changes and, of special importance to the late Middle Pleistocene, *how* similar technical developments emerged in different areas of the globe and how they diversified, leading, finally and unequivocally, to the construction of territorial identities defined by the cultural productions of the hominins occupying these lands (Barsky et al., 2018). Here, we use the HVDM model to pinpoint the basic structures of the Late Acheulian, with special reference to some well-known sites, to illustrate the major processes upon which our techno-evolutionary model is based: that of sequencing and that of bifurcation, without which the Dynamic Evolutionary Continuum (DEC) would not exist. We situate the shift from asymptotic to unbounded technical behavior in this part of the world at around 500-350 Ka; when the production of lithic tools exceeded the perfunctory, entering into a phase of intense cultural multiplicity.

1. Methods: The HVDM Model

According to the HVDM model, changes we observe in lithic assemblages through time are considered from the point of view of four fundamental concepts: homogeneity, variability, diversity and multiplicity (Carbonell, et al. 2009). Although the last three of these concepts can be considered overlapping, they are convenient to demarcate incremental differences within each broadly-defined evolutionary stage; from the (hypothetical) 'Mode 0' phase (Carbonell et al., 2018), through to the Oldowan (Carbonell et al., 2009) and Early Acheulian (Carbonell et al., 2016) and into the Late Acheulian (Barsky et al., 2018 and present paper). The model conveys specific technological developments that contributed to the growth of human industrial and social processes, as interpreted from the prehistoric archeological record. After around 2.6 million years ago, these records show relative stability of the Oldowan techno-complex (Semaw, 2000) until *ca*. 1.75 Ma (Lepre et al., 2011; Beyene et al., 2013), when the toolkits were entirely transformed (Oldowan-Acheulian transition in Africa), acquiring very different characteristics over time and initiating the *Dynamic Evolutionary Continuum* (DEC). Around this time (Dmanisi, Longuppo, Gabunia et al., 2000; Han et al., 2016), or possibly even earlier (Dambricourt-Malassé et al., 2016), tool making hominins occupied territories beyond Africa, a circumstance that may be attributed to technological progress and the resultant social, cultural and economic repercussions (Carbonell et al., 2010), although other factors are not to be excluded (Prat, 2018). In Europe after this time, more heterogeneity and even very substantial technological complexity are observed as hallmarks of the cultural materials (Orce, Titton et al., 2020) even as the LF Acheulian gained techno-morphological stability (Mosquera et al., 2016; Bourguignon et al., 2016). Throughout the European Acheulian, toolkits manifest important changes in hominin behavior, as socialization processes were adjusted to fit with expanding demography and larger individual group size.

1.1 State of the art

- ***Homogeneity***

The appearance of stone tool making in the African Late Pliocene (Lomekwian), can be explained as resulting from a previous behavior, in which some hominins (early *Homo*, but also *Australopithecus* and *Paranthropus*) were already using stones in similar ways that some primates do today, most notably, to execute hammering activities for resource acquisition (bone breakage, nut cracking). From this viewpoint, we argue that, over time, hominins experimenting with percussive activities would have 'incidentally' discovered advantages in intentional modification of stone. Hominins discovered and tested first technical 'systems' that emerged from a period of stone use of unknown duration, as they found uses for stone waste accidentally generated by percussive/throwing activities. This, so-called 'Mode 0' remains hypothetical because inadvertently produced artefacts lack identifiable features of systematic stone knapping.

- ***Variability***

By 2.6 Ma, hominins had invented the simple stone reduction modes that we attribute to the Oldowan. They discovered new ways to use both the large-sized percussion tools and the smaller stone chips they produced, widening their range of activities and gaining a marked evolutionary edge over other large carnivores with which they shared the landscape. Thus began what we describe as Oldowan morpho-technical variability, whose structure we have shown to be incipient to the possible and probable morphologies obtained by unidirectional and orthogonal knapping strategies and whose effectiveness led to a very long period of technical equilibrium. In Africa, Oldowan stone toolkits are sometimes found in association with large mammal fauna bearing traces of butchery with stone tools (e.g. Sahnouni et al., 2013). Toolmaking behavior proliferated and was transformed it into a tradition lasting over one million years (Braun et al., 2019; Semaw et al., 2000, 2003, 2009; Parés et al 2014; Sahnouni et al 2018), even persisting after the onset of the Acheulian in some areas (Beyene et al., 2013; Uribelarrea et al., 2017; Semaw et al., 2020). In spite of its technological stability, some innovations are now recognized within the Oldowan

(Hovers and Braun, 2009), reflecting the mastery gained by hominins experimenting rock fracture mechanics and adaptations to different contexts, raw materials, animal resources, climates and landscapes. Even the oldest toolkits are indicative of seemingly precocious technical knowhow (Stout et al., 2005). Systematic toolmaking during the Oldowan was an adaptive choice that had very significant repercussions for early *Homo*, improving the likelihood of obtaining protein-rich morsels from carcasses (Domínguez-Rodrigo et al., 2012) necessary to nourish the expanding brain. While Oldowan technology reflects a fixed range and limited set of well-defined core management systems, these provided sufficient variability to establish a solid foundation for well-defined sets of structurally associated gestures and behaviors, finally breaking the paradigm of homogeneity with open-ended operative schemes (see Figure 1 in Carbonell et al., 2018) that would unlock new potential for technological change.

- ***Diversity***

The techno-morphological specificity inherent to the operative schemes thus provided the potential to transform even the very stable Oldowan, eventually engendering the more diverse techno-systems of the Early Acheulian (Carbonell et al., 2016). Structurally, this occurred by: 1) unidirectional recurrent stone reduction dictated by cobble shape; 2) the length of knapping episodes and 3) the plasticity of the angle of edges intersecting orthogonally-oriented removal negatives on cores (see Figure 6 in Carbonell et al., 2016). Gradually, this morpho-technological plasticity enabled transitions to occur, increasing tool diversity and consolidating standardization (Developed Oldowan and Early Acheulian, Large Flake-based tools, PSSBs, small retouched toolkits, Leakey, 1971). Surely because of condensed resolution of the archeological records, such changes appear to have occurred spontaneously in areas previously occupied by Oldowan-producing hominins (see Figure 1 in Barsky et al., 2018). African stone toolkits dating from around 1.5 Ma exemplify new stages of technological achievement defined mainly by: prepared core technologies on giant to medium-sized cores and LCT shaping (Kleindienst, 1962; Isaac, 1986; Sharon, 2009 and references), bifacial knapping, bifacial/bilateral symmetry and tool standardization (Peninj, Gadeb, Melka Kunturé, FLK West Bed I and in Bed II at Olduvai Gorge, Konso Gardula, de la Torre et al., 2008, 2011; Diez-Martín et al., 2015; de la Torre and Mora, 2005; Beyene et al., 2013); all hallmarks of the Acheulian. This diversity, born out of human technical and cultural accomplishment over time, triggered very significant Acheulian techno-typological and behavioral changes quasi-synchronically in Africa, India, Southeast Asia, the Levant (*ca*. 1.75-1.5 Ma). Meanwhile, the Large Flake strain of the Acheulian, documented in Africa, India and the Levant (Sharon, 2009), had only limited diffusion into restricted areas of Europe in different timeframes, notably: the Iberian Peninsula and parts of southwestern France (Sharon and Barsky, 2016; Bourguignon et al., 2016). Oldowan variability was thus transformed and disaggregated as the system led to the production of new morphologies and technical structures presenting new adaptive advantages to the hominin artisans.

The techno-social changes materialized during the Acheulian had extraordinarily far-reaching effects upon hominin life. Following the LFA phenomenon, the archeological record shows significant demographic expansion of *H. erectus s.l.* (Carotenuto et al., 2016) and, moving through time, an ever-increasing density of individual site contexts, indicative of the augmenting individual group sizes. These observations lead us to conclude that, not only were hominin groups coming into contact far more frequently than during the previous Oldowan period, but they must also have been revolutionizing their internal group organization to accommodate the rise in number of individuals per group. A correlation is established between the social complexity implied by larger group size and increased selective pressure for neocortical development (Dunbar, 1992; Stout, 2019). More diversity in cores and tools, which were standardized through time, led hominins to further develop notions of culture and tradition. This is clearly demonstrated for example, at the localities of the Konso Gardula site (Main Ethiopian Rift, Beyene et al., 2013), where a wide chronological sample of the Acheulian techno-complex is recorded (~1.75 to < 0.85 Ma). The authors recognize distinct trajectories in the shaping strategies and final morphologies of LCTs, noting especially the refinement of handaxe morphologies through time (workmanship in edge modification, tip thinning, *some standardization of edge and tip shape/form*). From 0.85 Ma, greater sophistication and achievement of three-dimensional symmetry is observed in the handaxes, with: *…a novel 3D standardization component not observed in the > 1.2 Ma Early Acheulean* (Beyene et al., 2013). Change thus characterizes the large chronological trajectory of the Acheulian techno-complex in these and other sites, where additional standards affect the morphology and technology of different categories of tools, in interrelationships with variations in raw materials, expanded patterns of mobility, concepts of standardization. A part from the large cutting tools, the assemblages generally tend to contain an ever-widening array of small retouched tools on flakes. Concerning the latter, a predominance of denticulate tool types is recognized in the earliest phases of the Acheulian that could be linked to a systematization of formal expressions of secondary knapped flakes (Zaidner, 2013; Barsky et al., 2013b).

- ***Multiplicity***

The consequences of this process are reflected by the consolidation of trends described for the previous phases and after around 1 Ma, the spreading of novel expressions of Acheulian culture into widely dispersed regions of Eurasia (Mosquera et al., 2016; Derevianko, 2006; Doronichev, 2008; Lumley & Tianyuan, 2008; Le Tensorer, & Muhesen, 1997; Xingwen et al., 2017). Acheulian-producing hominin populations continued to rapidly radiate beyond the foyer areas (Barsky et al., 2018), developing complex networks of diffusion especially after around 1.0 Ma, as populations enlarged and hominins occupied an even wider territorial range, seemingly reaping the adaptive advantages provided by their toolkits. The characteristics and motives for this expansion is discussed in the present paper as the *Multiplicity* phase, taking into account the evidence from single and multi-level sites of the later Middle Pleistocene and the plentiful open-air fluvial contexts (Chauhan et al., 2017). The archeological register indicates that the LF Acheulian diversity developed into -or was replaced by- the Late Acheulian, eventually spreading into Europe (Sharon and Barsky, 2016) and beginning a new era marked by a wide-ranging cultural conservatism with idiosyncrasies that can be linked to specific territories. In this paper, we explain this multiplicity by examining the defining characteristics of its structural elements and the many expressions that form a part of the synthetic whole that is the Late Acheulian. Using examples from the European archeological record, we illustrate how different structures coexisting during the Late Acheulian contributed to forming a coherent, open-ended cultural system by incorporating advancements in technical, social and behavioral knowledge, allowing to exponentially expand and renew the potential for further advancements, while maintaining a cohesive substratum.

3. The structure of Late Acheulian techno-typological multiplicity

The technological diversity previously described for the Early Acheulian (Carbonell et al., 2016) established a foundation for the production of a new series of configurations in stone, launching a phase of innovation lasting over a million years, while maintaining coherency through cultural conservatism of some aspects of the toolkits (i.e. bifaces) (Finkel & Barkai, 2018). The HVDM explains that technological features of some EA morphologies, such as those observed at the 'Ubeidiya site (Bar-Yosef & Goren-Inbar, 1993), are technologically linked to recurrence inherent to the orthogonal knapping systems (see Figure 6 in Carbonell et al., 2016). After this development, the basic range of geometrical forms cut into stone was improved, as hominins began to more systematically manufacture morphologies to fit the new operational templates. The EA, consolidated in Africa and the Levant around 1.6 Ma and chiefly associated with *H. erectus s. l.* (Cachel & Harris, 1998), marks a clear break with the preceding Oldowan stone toolmaking phase by virtue of the materialization of new sets of pre-determined morphologies that we group here into two main categories: 'elongation' and 'sphericization' (Fig. 1). Elongation was achieved firstly after a shift from orthogonal core management systems to bifacial ones, in which the angle of the sinuous edge created during knapping and separating two opposed core surfaces, was modelled to be relatively more acute (Carbonell et al., 2016). This edge served as a guide to bifacial and trifacial surface exploitation, most typically expressed in the diversity of discoid- and Levallois core types (Boëda, 1993), which, in addition, sometimes morphed into pointed morphologies, notably in the form of picks and then as rudimentary bifaces (Beyene, 2013; Carbonell et al., 2016). Such morphologies are recognized in pre-Acheulian assemblages, for example, during the Developed Oldowan (Leakey, 1971; de la Torre & Mora, 2014). With the move to the production of larger-sized flakes (Isaac, 1969), so too did cleavers emerge as an emblematic LFA tool type, whose prominent active feature is the extended dihedral edge obtained by an impressive array of (often complex) prepared core technologies (Sharon, 2009 and references). While frequently lauded as emblematic of the emergence of the Acheulian (in the broad sense), symmetry is not, in fact, characteristic of its first materializations (Hodgson, 2009). Apart from the production of large flakes already mentioned, it is the modelling of pointed morphologies that more adequately characterizes this shift. It should be noted that pointed morphologies that typify 'elongation' are present, not only among the group of LCTs, but also amongst the retouched toolkits that also witness substantial morpho-technical expansion during this phase.

Secondly, as pointed out by Carbonell et al., (2016), the HVDM model pinpoints multidirectional core management, which also emerged out of the Oldowan, as another central innovative strategy permitting advances towards a tool grouping grounded in the geometric notion of 'sphericization'. In this case, spherical forms (PSSB group, Texier & Roche, 1995) experimented in the Developed Oldowan (or Late Oldowan, de la Torre & Mora, 2018), were manufactured by regularly effectuated core rotations while maintaining more obtuse angles between the flake negatives (Barsky, 2009). Such knapping methods and the resulting tools are the development of previously established procedures already in place at sites like Ain Boucherit (Algeria, Sahnouni et al 2018). Shape-intentionality in this method, generally applied to non-dominant raw material types within each assemblage, tended towards the production of polyhedron and globular core types, as well as the (rather more sporadic) sub-spheroids and spheroids, and the occasional bola (extremely rare in the European context, Titton et al., 2020) and lasting even into the Late Acheulian of the Levant (Barkai & Gopher, 2016)- perhaps recuperated from older Acheulian contexts (Assaf et al., 2020). Finally, with the invention of clearly distinguished tool types within this grouping (i.e. true spheroids and bolas), raw materials were purposefully chosen to fulfil specific functions within the manufacturing operative schemes, based now not only on technological, but also on typological categorizations: these behaviors are developed from distinct patterns observed in the Oldowan techno-complex.

The structural foundation generated during the early stages of the Acheulian (Fig. 1) is characterized by elongated (pointed) and spherical (cubic) forms that provided a broad potential from which to develop new morphologies (relative to the Oldowan variability). In the latter case, as demonstrated in Carbonell et al. (2009), techno-morphological potential was organized around the more restrictive unidirectional and orthogonal knapping systemic and products lack premeditated shaping (at least up until the later phases of the Oldowan). After the appearance of the EA around 1.7-1.6 Ma in Africa (Asfaw et al.,1992; Beyene et al., 2013; Kuman and Clarke, 2000; Uribelarrea et al., 2017, and others), India (Pappu et al., 2011) and the Near East (Bar-Yosef and Goren-Inbar, 1993), high morpho-technological stability was reached during the LFA, where the new assortment of geometrical forms was produced with regularity by way of different prepared giant core technologies. Sharon (2019) provides an overview of these diverse and highly sophisticated methods of LF production from the different regions of the globe, identifying at least seven distinct giant core strategies: *Slab slicing, Bifacial, Entame, Kombewa, Levallois, Victoria West, Tabelbala-Tachenghit*; underpinning technological diversity, while at the same time demonstrating the extraordinary morphological homogeneity of the products themselves: large flakes for making bifaces and cleavers. Sharon (2007, 2009) explains this phenomenon as a probable example of convergent evolution wherein "*Acheulian toolmakers had a cleaver and handaxe 'mental template' that determined the lithic technology most suitable for use with available local rock types, shapes and sizes in the production of these tools*" (Sharon, 2009). For some, the diversity of the technologies and the structural homogeneity of the final tools over vast regions of the globe marks the beginning of a long phase of cultural conservatism.

The consistent features of the final products obtained using different knapping strategies, emerging in the EA and then perfected in LFA assemblages in widely separated areas of the globe (South, North and East Africa, the Near East, India), comforts the hypothesis of cultural convergence. This indicates: 1) the changes that materialized in the EA toolkits had progressive adaptive repercussions, that ensured their techno-evolutionary continuity as reflected by increased demography after 1.5 Ma; 2) the integration of mental templates corresponding to this new phase of technological achievement was fully assimilated, socialized and transformed into 'traditions', which, through time, evolved to show variations in accordance to their regional context (see point 3.- below). After its emergence, the Acheulian spread rapidly (Moncel et al., 2018a, 2018b, 2018c). By comparison to the Oldowan. Its proliferation was an unprecedented phenomenon that (we argue) can be considered as the first major, demographic, socio-cultural revolution of humanity. Also for the first time, Acheulian material culture encompassed specific manifestations of human abstract notions. It therefore expresses "culture", defined as a set of behaviors and traditions that are shared and transmitted by members of social units that, in this timeframe, were likely organizing themselves into hierarchized groups. As they settled into different regional contexts, Acheulian peoples developed their own sets of cultural behaviors within the widening foundations of their expanding techno-systems. By around 0.8 Ma, more than half a million years after its inception, the LFA was replaced by the (relatively more abundant) Late Acheulian (Sharon & Barsky, 2016), with considerably more diverse toolkits *with or without handaxes*, sometimes containing far more numerous lithics. Small retouched tools are also very frequent, with toolkits containing many scrapers and frequent pointed tool morphologies. Innovations of the LA spread throughout the Old World (including Asia and Central Europe), with unprecedented and far-reaching manifestations. By around 0.4 Ma we observe that some of its multifaceted expressions were already tending towards the transition to the Middle Paleolithic (Tabl. 1):

From our point of view, the unprecedented proliferation of the LA can be understood to have radiated from the inter-relation of three factors, all linked to technological progress consolidated through time: 1.- demographic expansion, 2.- the consolidation of land-linked traditions and 3.- the controlled use of fire and the communal notion of hearths:

<u>1.- Demographic expansion</u>

The persistence of the LA record, extending chronologically throughout Eurasia up to MIS 6-5, shows that, in the face of cyclical climatic change, when populations might have dwindled or expired locally, there was a sufficient core-population to maintain and establish denser population networking than in all previous stages. As a result, we surmise that the ever-quickening pace of techno-social developments characterizing the latter phases of the Acheulian resulted largely from increases in inter-group contacts that would have occurred in synchronicity with the surges in population density and corresponding geographical expansions. Cultural transmission through social networking whereby different groups would logically have more frequently come into contact, catalyzed technological innovation in cultural materials (Barsky et al., 2018). The increase in social networking created thus an autocatalytic system, whose retro-alimentation engendered contrasting cultural features within the global multiplicity of the Acheulian techno-system. Evidence from numerous Western European sites, reveals important shifts in hominin mobility in relation to climate during the LA in Europe, illustrating how increases in techno-forms and the idiosyncratic variants they show in different regions, might actually be revelatory of important changes in the perception that these hominins had of the meaning of their own cultural practices. In Europe, unparalleled success of LA peoples compared to all preceding populations can be attributed to several biological and social factors. Concerning the former, this timeframe bears witness the separation of an independent lineage of the *H. erectus* clade, which was the origin of some species like *H. antecessor*, *H. heidelbergensis*, *H. neanderthalensis*, *H. sapiens*, and the elusive Denisovans (Bermúdez de Castro and Martinón-Torres, 2019). Furthermore, *H. erectus* would have been the origin of *H. floresiensis* (Morwood et al., 2004) and *H. luzonensis* (Détroit et al., 2019) by isolation processes. All these hominins present a range of anatomical and cerebral features that arose as adaptations for survival in a variety of specific regional contexts. Studies of ancient protein sequences, for example, have recently brought to light genealogical relations between *H. antecessor*, Neandertals, Denisovans, and modern humans (Welker et al., 2020).

Concerning the social factors at play, increases in hominin congregates would necessarily have demanded inter-group prioritization and sharper designations of role playing. Advances in the field of cognition have established links between the development of language and stone-tool making, demonstrating the need for verbal teaching in order to transmit the knowhow necessary to manufacture the more elaborate tools of the Acheulian, compared with the simpler Oldowan techniques, which can be learnt through imitation and without requiring verbal cues (Morgan et al., 2015). While animals communicate their mental states and share information through sounds, expressions, and gestures, humans have further evolved these cognitive processes by intimately linking them to spoken language, making it a central means by which knowledge is acquired and shared. The learning of Acheulian techno-forms requires both abstraction and memory, moving beyond the animal realm of instinctive reaction and basic learning skills, into that of symbolic communication and technological capacity as a compound socialized process. The links between vocal language (understood as a system of communication that uses symbolism to convey meaning) and manual praxis are confirmed by studies in cognitive neuroscience that show that the 'language relevant' areas of the brain situated in the frontal cerebral cortex are 'coopted' to perform a variety of non-language behaviors relative to tool-making (object manipulation, prediction of sequences, visual search, etc., Stout and Chaminade, 2011). The range of Acheulian tool types and, especially, their standardization, would have required considerable time investment in terms of imparting knowledge that would have had repercussions on the development of relationships within the hominin groups.

Finally, as shown in Fig. 1, tool-making was certainly not the only innovation to have revolutionized the socialization processes into the LA and hominins were achieving other, very significant innovations implying increasingly heavy investment in developing venues for symbolic communication were being enhanced, to which we may only, in the agenda of this paper, pay lip service. Among these, organized predatory expeditions are especially noteworthy in the framework of the present discourse. Attested in Western European LA sites from as early as MIS 12-MIS 14 (respectively), such as; communal hunting of bison in Gran Dolina TD10.2 (Sierra de Atapuerca, Spain, Rodríguez-Hidalgo et al., 2017) and selective reindeer hunting in Level L of the Caune de l'Arago (Tautavel, France, Barsky et al., 2005; Moigne et al., 2006). Communal hunting involves organization and planning, knowledge about the prey's behavior, biotope and habits. Furthermore, as underlined by Stringer (2012), they involve far-reaching social implications, such as developed social signalization, cooperation, cunning and the ability to predict the behavior of hunting companions. This latter "mental reading ability" would have fostered the development of symbolic gestures in order to communicate from a distance during hunting expeditions.

2.- Consolidation of land-linked traditions

As populations increased, LA traditions were intensely transformed through complex networks of diffusion and socialization as populations amplified into different regions, adapting their toolkits in relation to both environmental and social circumstances. The demographic expansion attested in the archeological record implies more frequent incidences of intra-group contact increasing the likelihood for cultural transmission (Diamond, 1997). One of the most obvious manifestations of this phenomenon is reflected by developments in the field of lithic studies over the last century, where we can observe the emergence of numerous LA cultural denominations that have been created to describe specific ‘types’ of toolkits observed to exist within clearly delimited geographical regions. These denominations were most often created from eponymous sites where such specificities were first recognized and defined. During this cultural phase, LA human groups confronted their regional-specific needs by choosing among the expanding number of technical solutions available to them from within the *Multiplicity* of the Acheulian techno-complex, forming new profiles of cultural expression in close affinity to the geographical area in which they were living. Cultural expression thus became intimately tied to specific geographical contexts; marking the birth of cultural identities. This fact is further underlined by the plethora of denominations for late Acheulian ‘cultures’ across Eurasia, each of which designates technological specificities defined (often at eponymous sites) within a specific geographical range. Some examples are the Clactonian from England (Breuil, 1932, Clacton-on-Sea), the Micoquian of southwestern France (La Micoque, Hauser, 1907) or the French Mediterranean Tayacian (l'abbé Breuil, Lower levels (4, 5), la Micoque, Dordogne). From this point, this *geographic-compartmental aspect* of human material culture became a defining factor of human civilizations, permitting them to separate into distinct cultural units distributed by geographical boundaries. This contrasting on a cultural level continues to define separations between human peoples up to the present time.

The very wide distribution of Late Acheulian peoples indicates that climate variation would have played only a minimal role in affecting their cultural multiplicity. Different manifestations of toolkits on the Lower/Middle Paleolithic boundary reflect rather a range of cultural filters. This cultural revolution embarked hominins on a new techno-social pathway as they tested the potential within their newly developed knapping systems involving hierarchical surface management and complex volumetric planning. These developments were equally marked by universal standardization in both production and tool morphologies. Cultural complexity thus became not only a way forward towards higher dexterity and renewed ingenuity, but also a way for groups to highlight their identities by means of individuality expressed through the object. In sum, LA multiplicity is attributable to the availability of a relatively wide structural foundation obtained through cumulative culture, (from which it draws its formal expressions), and from networking/cultural exchange. That is why LA assemblages may contain all or only some of the defining features attributed to the Acheulian techno-complex.

Humans instinctively explored the mechanical and structural possibilities of their technological knowhow and experiments fed into the dominant, global techno-pool, within the specific formal range of the Acheulian *s. l.* Continued testing eventually broke up the stability of the techno-system, with newly developed morphologies and their associated behaviors spilling over into a new range of technological expression of the Middle Paleolithic. Intensifications in communication networks (linked to demography) led to enlarged sharing/exchange of technological innovations on an ever-widening geographical scale because they favored the competitive success of human reproduction and survival. They spread with increasing rapidity due to enhanced social skills that humans were developing in synchronicity. The combination of these phenomena are key to understanding techno-genesis as a system that grows and fluctuates alongside social forces and augmented population density. All have favored humanity's evolutionary successes and the unbridled development of technologies. This process inextricably occurred through both acculturation and convergence. Accumulation is the dynamic force that causes technical systems to reproduce themselves with increasing rapidity, as the weight of the potential represented by pooled technological knowhow becomes progressively more massive: the 'heavier' this content is, the more consequential the overflow will be.

3.- Operative control of fire and the collective perception of hearths

There is consensus that the ability to make and control fire is among the most important and transformative technological milestones achieved by early humans during the Acheulian (Roebroeks & Villa, 2011). The earliest evidence for intentional burning in a constrained archeological context is documented around 1 Ma, in the Acheulian strata of the Wonderwerk Cave site in South Africa (Berna et al., 2012). However, there are some reports of fire from older, open-air sites in Africa (Gadeb 8E, Koobi Fora FxJj 20 East, Chesowanja GnJi 1/6E, Members 3 at Swartkrans: Gowlett et al., 2016; Clark & Harris, 1985; Brain and Sillent, 1988; James et al., 1989; Bellomo, 1994). This evidence is supposed to signify *passive use of fire* (Sorensen, 2019), an early phase proposed in the evolutionary process of the human understanding of fire, wherein brazes might have been collected, transported and preserved, preceding *active control of fire*. For now, none of these sites has yielded evidence for the actual production of fire, for example, by the presence of hearth structures (*constructed combustion features* (Roebrooks and Villa, 2011), that would indicate that hominins were systematically making and using fire in the context of occupational settings (which, in any case, are poorly identified in this timeframe). Differentiating intentional fire-making from opportunistic use of fire presents obvious difficulties to archeologists and in these, very ancient occurrences, evidence of fire may be attributed to scenarios in which it was gathered from naturally kindled blazes, such as those ignited by lightning, original pyrogenic settings, or spontaneous combustion (Rolland, 2004).

Controlled use of fire (*the ability to set fire at will*, Alperson-Afil, 2012) is recognized outside of Africa (at first sporadically) from around 0.8 Ma (at GBY in Israel, Goren-Inbar et al. 2004) and then from some sites attributed to around the MIS 12, when fire is more systematically associated with later Acheulian peoples in Europe (at Terra Amata, Lumley, 2006 and Menez Dregan, Ravon, 2019) and especially, around 350-300 Ma in the Levant (at Tabun and Qesem caves, Shimelmitz et al., 2014; Karkanas et al., 2007), and elsewhere (Roebrooks and Villa, 2011). In China, direct evidence for *in situ* burning reported from levels dating to 800-600 Ka at Zhoukoutian (Gao et al., 2017). Genuine hearth arrangements are documented in Africa and Eurasia during and after this timeframe and become a prominent feature in many of the sequentially inhabited later LA sites with a high density of archeological materials

(Barrosso-Ruiz et al., 2011). These sites appear during the Middle Pleistocene, when hominins ranging within more clearly delimited regional contexts developed new social and economic strategies, notably with the concept of provisioned base-camps repeatedly inhabited over generations- and even over millennia (Rolland, 2004; Gopher & Barkai, 2010; Shimelmitz et al., 2014; Chazan, 2017). Such, home-base provisioned occupations became even more pervasive from the Lower-Middle Paleolithic transition during the Upper Pleistocene (esp. after 200- 100 Ka) (Valensi et al., 2013; Rosell and Blasco, 2019; Vallverdú et al., 2012).

While it is convenient to establish a relationship between the presence of hearths and the increase of rock-shelter and cave occupations, perceived in the archeological register, this postulate may indeed be biased by geological factors, which, in turn, depend on the preservation of fire indicators (charcoal, carbonized rock or sediment, charred artifacts) and our ability to detect them in different site contexts, a condition that is understandably more likely to occur in archeologically controlled enclosed cave settings (Roebrooks and Villa, 2011). In open-air contexts, the possibility for naturally-induced fires to affect archeological sites and materials often challenges authentication of anthropogenic origins for fire evidence. Nevertheless, it is noteworthy that hearths have also been detected in some LA open-air, water-edge sites, such as Terra Amata in France (Lumley, 2006), Beeches Pit in England (Gowlett, 2006) and Bilzingsleben in Germany (Mania, 1991), while conclusive evidence is lacking from others (e.g. Schöningen, Stahlschmidt et al., 2015). Hearths are conspicuously absent at other important Western European cave sequences, for example, at the

Caune de l'Arago and Atapuerca's Middle Pleistocene sequences (Barsky et al. 2019; Lumley et al., 2015; Ollé et al., 2013), whose deposits cover much of the latter phases of the Middle Pleistocene, suggesting that fire-making could have taken place outside of the caves, or that it was not an indispensable survival strategy for the hominins living there. Alternatively, the absence of hearths may indicate other schemas in which fire-making within provisioned home-bases, hunting halts or other habitation types recognized for these particular sites was not integrated into social or cultural norms of specific human groups sequentially occupying these spaces. In light of the relative cultural multiplicity and regional variability attested for the LA, and in agreement with Shimelmitz et al. (2014), such cases should be considered in terms of 'regional population', rather than forcing relationships across wide-reaching geographical areas based on chronological analogies.

Presently, spatial distribution of burnt bones and lithics allow to establish relationships between the identified activity zones and the general layout of sites with hearths or mega hearth structures, revealing organizational stratagem within the habitats, which, in some cases, was maintained over millennia (Barrosso-Ruíz et al., 2011; Shahack-Gross et al., 2014). It is evident that the controlled use of fire contributed prominently to the lifeways of the Acheulian peoples, and its evolutionary impact must have greatly affected the survival and reproductive success of human groups. Fire-making is often cited to explain the capacity for Acheulian hominins to enter and settle into parts of northern Eurasia, where they would have encountered temperate and even very cold climatic conditions with considerable temperature and humidity oscillations through time. However, as discussed above (points 1 and 2), a number of Acheulian sites discovered in high latitudes are known to pre-date the chronological range now proposed for active fire-making capabilities (MIS 12-11), reinforcing the suggestion that other aptitudes had already enabled hominins to adapt and adjust to harsh climates at earlier dates. While some hypothesize that even if hominins thriving in open-air Boreal contexts in the northern regions of Eurasia prior to this age-range (in England 0.8-0.5 Ma: Happisburgh 3; Boxgrove, Highlodge, Parfitt et al., 2010; Roberts & Parfitt, 1999) were occasionally making and using fire, the evidence for these activities remains persistently elusive to archeologists (Gowlett, 2006). Meanwhile, others have argued (as we do) that the habitual use of fire was not prerequisite to human survival in these timeframes and territories (Roebroeks & Villa, 2011; Stahlschmidt et al., 2015).

Whatever the scenario, it seems likely that, prior to MIS 12 Acheulian peoples were opportunistically manipulating fire in different ways. As with other technologies, human interactions with fire (Gowlett and Wrangham, 2013) would have led, through cumulative knowledge and experimentation, to the capacity to make and control it, as well as expanding its uses as a transformative tool. There is no doubt that once fire-making proficiency was attained, it engendered significant changes in human lifeways, facilitating settlement in all areas of the globe. Experimenting with different uses for fire included heating different types of materials to test their physical reactions and, of course, seeking utility in their resulting transformative features. Thus, fire was useful to improve some aspects of tool-making, for example, for hardening wooden weapons

(Schoch et al., 2015) and later, for making adhesives (as for hafting, Mazza et al., 2006) Highly significant among these innovations was the transforming of foodstuffs, in particular meat, through cooking. Cooking meat would have provided numerous advantages to hominins (Wrangham et al., 2009), among which, reducing the risk of contracting diseases carried by parasites (Berna et al., 2012) and speeding up and facilitating the ingestion of calories, favoring rapid development of the brain's neocortical regions necessary for the sharpening social skills required to manage the expanding social networks. It also changed the scheme of rapid food ingestion on kill sites to food sharing concentrated around fires, *which became attractive locations for increased social interaction between individuals* (Roebroeks & Villa, 2011). Another point is that the controlled use of fire would have provided a formidable weapon for hunting and trapping game, while at the same time providing protection from predators and assuring safety within the provisioned home-bases.

A vital aspect of this process involved the reinforcement of symbolic means of communication and the strengthening of social ties, favoring optimum communication whose expanding efficacy explains the relative rapidity with which this novel expertise spread. The enlargement of social complexes, combined with skills gleaned from ever more perfected technologies enabling optimal exploitation of (even changing) environmental niches, expanding language-symbol communication to facilitate social ties and inter and intra-group functionality, all prepared hominins to reap the survival benefits provided by fire-making. All of this surely could not have taken place had humanity not reached the required state of readiness prerequisite to these inventions:

readiness in terms of accumulated technological knowhow and in terms of the efficacy of social diffusion networking. We conjecture that fireplaces became a hub of community life within the base-camps. Glowing embers of hearths permitted prolonged social interaction into the night, certainly favoring linguistic and other forms of symbolic story-telling, sharing and exchange of events that would eventually evolve to formulate myths and forging social identities into tradition. The habitual use of fire recorded from the latter phases of the Middle Pleistocene onwards fueled the development of cultural identities within and between human groups; catalyzing symbolic sensitivities, as social lives became more carefully structured around the technological multiplicity.

Conclusions

This paper focuses on the European Late Acheulian as representative of cultural Multiplicity, in accordance to the HVDM model. This model examines the structural foundations at the root of early human cultural evolution to explain the morphologies diversely described in global prehistory. We provide a review of the different stages of technological and behavioral developments, from the emergence of first technologies in Africa some 3 Ma, through the Oldowan- in its African and Eurasian contexts –and then into the long and stable Acheulian techno-complex. This allows us to finally discuss how cumulative cultural paradigms gained strength during the Late Acheulian, mainly through intensified inter-communicative networks taking shape as a result of increases in demographic trends. The different hominins present in Western Europe during the Late Acheulian (MIS 12-9) confronted changes in climate and environment but also re-shaped their social behaviors in relation to their rapidly advancing technological prowess that was to take on multiple forms while remaining within the Acheulian framework. Base-camp type habitats were frequent during this timeframe as hominins, now organized into social groupings, maintained cultural expressions in relation to the territories they roamed, returning over many generations to occupy the same-sites. Fire-making was key to changes observed in diet and comportment, revolutionizing hominin lifeways as they adapted to a new and more complex social existence, now heavily reliant upon communication networking, internal social classification and, especially, the contrasting of subtle cultural differences between groups living in different geographical areas. The repercussions of fire-wielding for humans were far-reaching in terms of the power it allotted them in relation to all other living species and perhaps also to one another. Fire also had ramifications that would continue to strengthen and deepen the growing corpus of symbolic communication-behaviors that would continue to model humanity thenceforth. Moving into the Middle Paleolithic, hearths became (gradually more structured) central areas of cave-sites that were frequented by hominin groups over millennia.

In spite of its formal Multiplicity, the Late Acheulian in Western Europe is a coherent cultural complex defined mainly in relation to *H. heidelbergensis*, a hominin presenting some presages of Neandertal features- both physical and behavioral. Toolkits may or may not contain handaxes and cleavers were scarce overall (with the exception of the Iberian Peninsula, arguably suggesting some kind of spatial-migration route from North Africa). Small retouched tools are profuse and hardly differentiated from those of the Mousterian toolkits. Knapping strategies are as diversified as the raw materials used, while mobility patterns reveal high flexibility within a fixed territorial radius (that was sometimes patterned and repeated over the ages). Site yields are higher than for all previous periods and butchered faunal remains (generally of smaller-sized game than previously) are present in higher ratios as well. The multiple manifestations of LA toolkits are explained by the wide foundation of tool types and knapping skills developed and exchanged over time and that were being implemented and transformed into distinct cultures. We have summarized these into two main groups, spherization and elongation, which provided the mental templates necessary to manufacture the range of techno-forms observed in Acheulian assemblages. During the LA, these forms were experimented and tested in relation to raw materials that were chosen precisely according to the type of product desired. Regional variations that came to exist within the limits of formal expression of this model were contrasted between populations settled in different areas into distinct cultural complexes. The interplay of the key influences of demographic expansion, consolidation of land-linked traditions, operative control of fire and the collective perception of hearths, intensified this process; on the threshold of the Middle Paleolithic.

There are, therefore, a whole series of factors that constitute what we have called the Multiplicity phase within the HVDM model. We refer to a specific evolutionary moment, in which multifaceted behaviors finally resulted from an exponential series of acquisition that are catalyzed in the operating systems of the Late Acheulian. In contrast to previous periods of human cultural evolution, Late Acheulian multiplicity was more largely driven by forces that were of cultural rather than biological origin. Effectively, we identify the exponential demographic increases recorded especially throughout the African and Eurasian continents between MIS 12-6 as the mechanisms of social change and transformation. Many lithic and faunal records, in caves, rock shelters and open air sites, underpin this generalized increase in hominin populations. This trend was accompanied by migration surges into new areas, as demographic pressures became linked to cyclical occupation of some territories by specific hominin groups. We argue that the range of hominin anatomical forms attributed to this timeframe are the consequence of sociodemographic expansion and retreat, in response to the continued reproductive successes linked to technological progress and cultural exchange.

Most likely, the first human occupational waves of the late Early Pleistocene formed relatively weak and poorly structured networks that only gave way to exponential growth just prior to MIS 12. In order gain this effectiveness, humans established networks that generated and reinforced spatial nodes. Hominins were only capable of resisting environmental pressures of these territorial nodules by generating a resilient structural framework based both on technical and social advances, such as, the establishment of main centers of interaction (home-bases), complimented by secondary food and raw material supply areas. This capacity to generate a range of occupational configurations favored and reinforced inter-group networking. This could only have been achieved through occupational redundancy (observed in multi-layer sites) that we assume, was at first seasonal and later social. This, generational return to same territorial ranges configured traditionally determined cultural spaces, which were finally expressed in morpho-technical and behavioral norms. The result was the authentic cultural and territorial maps that we have assembled based on the archeological data and that reflect the maintenance of inter-population linkages over long periods of time. The 'cultural entities' built during the Late Acheulian were structured enough to resist to some extent the effects acculturation (they maintain affinities with the Acheulian techno-complex), at least for long periods of time.

Differentiated spaces designated for specific activities also opened up many possibilities for acquiring new behaviors, for example, in alimentation and (in general) subsistence patterning, but also in technicity and in the forms of socialization. The innovation of fire as a technique, produced, (with fairly certain probability), largely intensified socialization, as well as changing the ways of obtaining energy from the environment. This translated into increases in group cohesion, feeding the cultural multiplicity observed in end-Middle Pleistocene archeological registers. Active control of fire, as attested by the presence of hearths that spread in almost all the occupations dating to this period and that would become even more consequential in Neanderthal sites, contributed to the developing aspects of symbolic communication, such as art. Deep investments were made at this time to adopt and develop abstraction and symbolism as a viable cultural strategy with which to deal with the human demographic explosion.

We conclude that techno-social multiplicity is the origin of modern behavior. Our brain, our ability to communicate with articulate and precise language and our technicity allowed this incredible increase in the speed of socialization. In this complex scenario, the accumulation of technological and cultural information reflected in the operational chains had finally become sufficiently robust and consequential to model the new operational fields of the Middle Pleistocene industries. In conclusion, demographic increase, regionalization and techno-cultural investment, reinforcement and structuring of networks with acquisitions such as fire, special treatment of the dead and the beginnings of art, all constitute phenomena that increase sociability, retro-alimenting a unique scenario that was to form the substratum of modern humanity and that was cultivated at an accelerating pace. In the HDVM theory, multiplicity is nothing more than the expression of human behavior shaped by random processes. The biocultural synthesis presented here is impossible to understand without taking into account the factors that have made human complexity possible through the exponential development of interactions between individuals of the same and different species, and their interfaces with the environment.

Author contributions

DB and EC for article conception and writing; J.M de C for significant written and conceptual contributions and F.J. G.-V. provided images and information from Santa Ana.

Data availability

Data is available from the present manuscript and bibliographic resources cited therein.

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Figure 1: Main techno-typological groupings of the Acheulian techno-complex and the tool categories they include. The illustration shows the relationships within the two main formal groups identified in Acheulian toolkits: spherization and elongation. Morphological concepts and operative themes are situated within these spheres and the relationships between tool categories are indicated.

Figure 2: Elongation. Examples of a handaxes and other bifacial tools from the Sierra de Atapuerca Gran Dolina Lower TD10.1 (A-D) and Upper TD10.1-A (E-G) (Lombera-Herida et al., 2020).

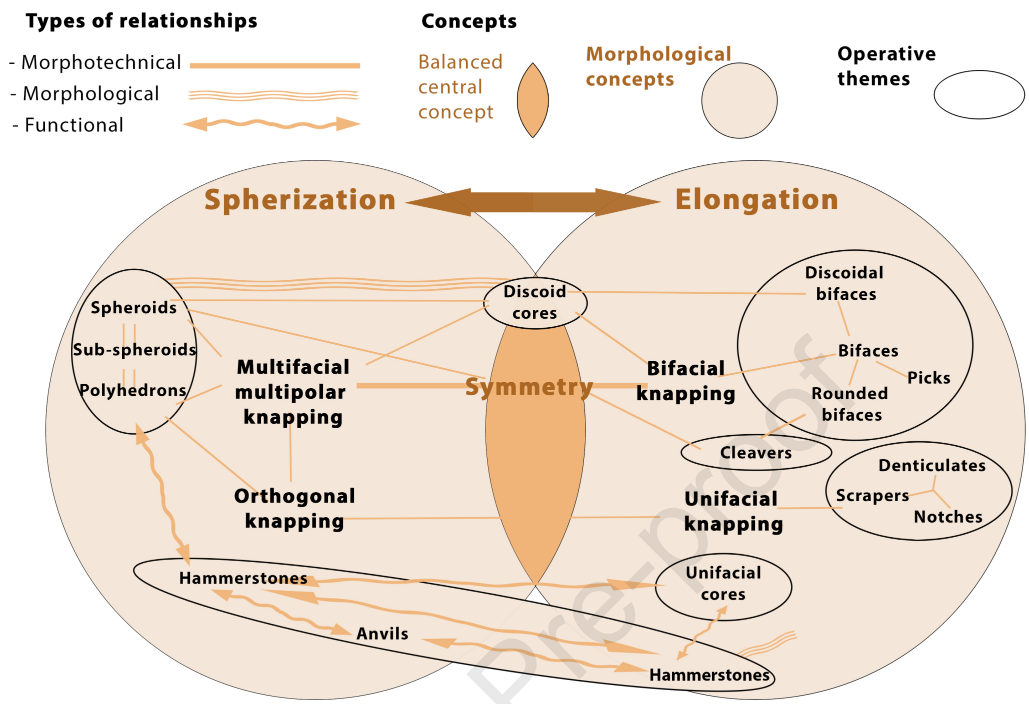
Figure 3: Elongation. Late Acheulian retouched tools in quartzite, Neogene flint and chert from Sierra de Atapuerca Gran Dolina TD10.1 (A-D: Side scrapers; and E-K: Pointed and convergent tools) (Lombera-Herida et al., 2020).

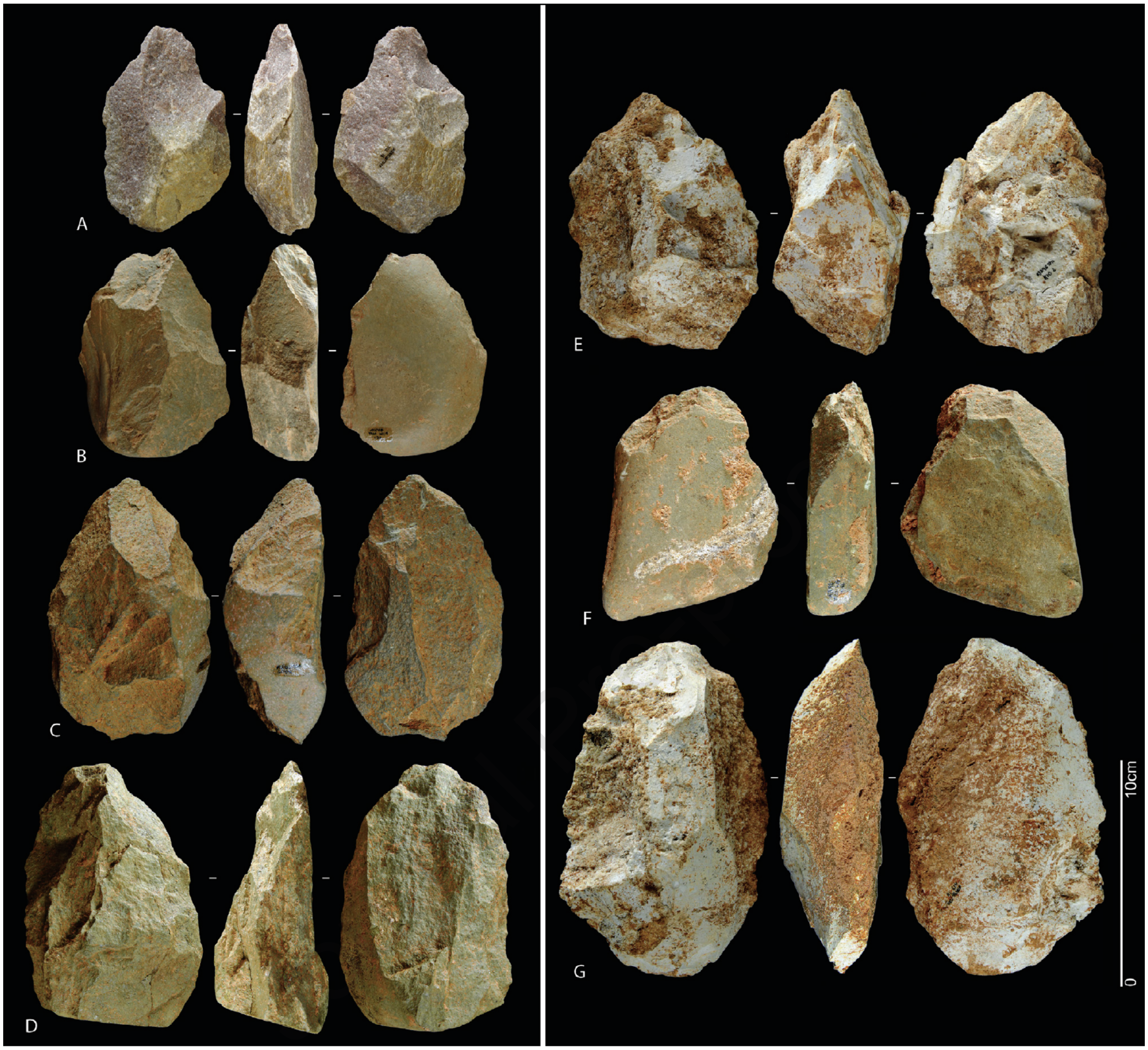
Figure 4: Elongation. Bifacially worked handaxe from Terra Amata (archeostratigraphic sub-unit D) with basal cortical reserve (Images: courtesy of Professor Henry de Lumley).

Figure 5: Spherization in the lithic toolkit from the Santa Ana cave: a) Quartz spheroid and (b and c) quartz cores. Photograph a) Sioba Grande; drawings (b- c) Néstor Sanchís published in (Carbonell et al., 2005); Francisco-Javier García-Vadillo edition.

Figure 6: Hearth 6 from Level XI of Bolomor Cave (Valencia, Spain) in excavation process during the fieldwork season 2008 (Photograph credit: Josep Fernández Peris, Servicio de Investigación Prehistórica (SIP), Diputación de Valencia, Valencia, Spain).

End Lower Paleolithic Late Acheulian	*FINAL LATE ACHEULIAN*	Beginning Middle Paleolithic Mousterian
Increased mobility & raw material variability		Decreased mobility preference for flint
Controlled use of fire		Abundant hearths in base-camp settings and occasional mega hearth structures
Organized hunting expeditions and scavenging of large prey		Organized hunting expeditions oriented mainly towards small to medium-sized prey
Prepared core technologies: discoid hallmark.		Prepared core technologies: Levallois hallmark
Cultural attributions linked to tool types/frequencies		Typological stability
Handaxes persist but no longer ubiquitous; cleavers disappear.		Handaxes progressively replaced by finely retouched bifacial pointed tools (and *pieces bifaciales*), no cleavers.
Retouched toolkits frequency of notched types		Frequency of scrapers and points
Cobble tools clearly distinguished from cores		Diminished frequency


Types of relationships
- Morphotechnical
- Morphological
- Functional
Concepts
Balanced central concept
Morphological concepts
Operative themes
Spherization
Elongation
Spheroids
Sub-spheroids
Polyhedrons
Discoid cores
Multifacial multipolar knapping
Symmetry
Bifacial knapping
Discoidal bifaces
Bifaces
Picks
Rounded bifaces
Cleavers
Orthogonal knapping
Unifacial knapping
Denticulates
Scrapers
Notches
Hammerstones
Unifacial cores
Anvils
Hammerstones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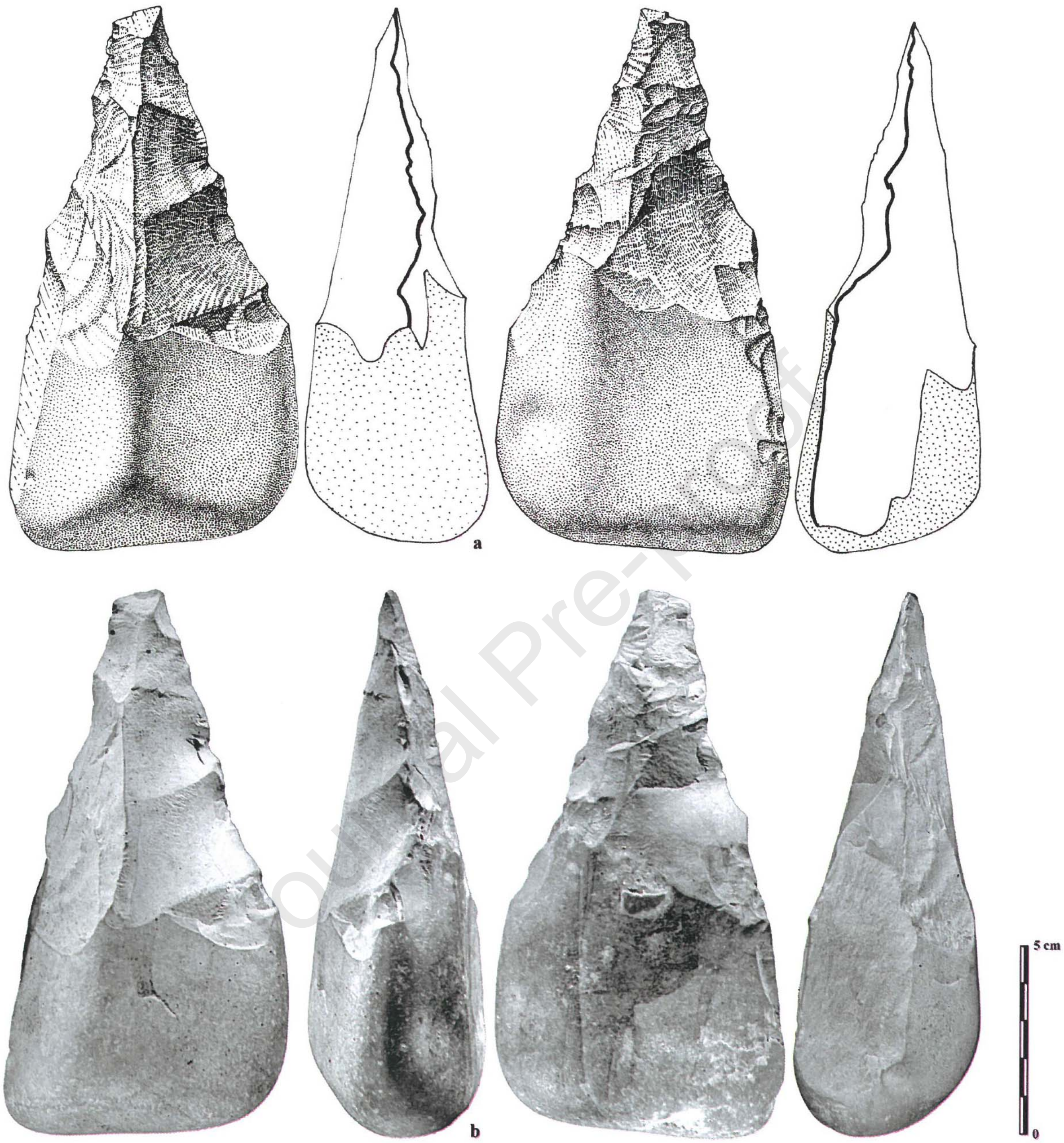
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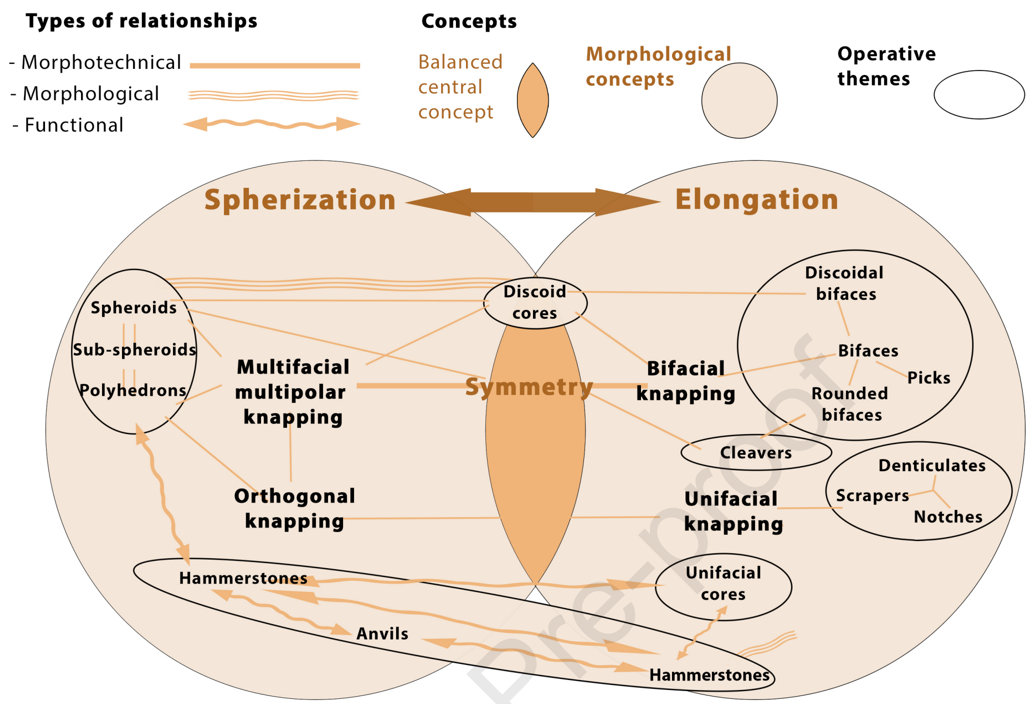
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Declaration of interests

√ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: