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Project Gallery

Project WEAR: a methodological framework for experimental and computational analysis of stone tool uses

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The WEAR project is developing integrative methods to analyse and predict use-related shape transformation of Neolithic stone tools from Central Europe through experimental archaeology and computational modelling.

Keywords: Western Europe, Neolithic, Linearbandkeramik, experimental archaeology, geometric morphometrics, functional analyses

Background

Bifacial hitting and cutting tools (axes, adzes, chisels) are prominent among Neolithic stone toolkits. They represent technological strategies developed during periods of fundamental change in human lifestyles, including the aggregation of large communities (Watkins 2023), the creation of built environments and stable settlements, and the domestication of plants and animals (Shennan 2018). In Central Europe, hitting and cutting tools are among the most common stone tool type in Neolithic assemblages, playing a pivotal role in the initial Neolithic occupation of the region, where woodworking for house construction was central.

In the Early Neolithic (Linearbandkeramik (LBK); 5600/5500–4900 BCE), two primary types of tools appear: the shoe-last celt and the flat adze (Figure 1). Despite standardised production across a wide area, our understanding of the technical choices behind

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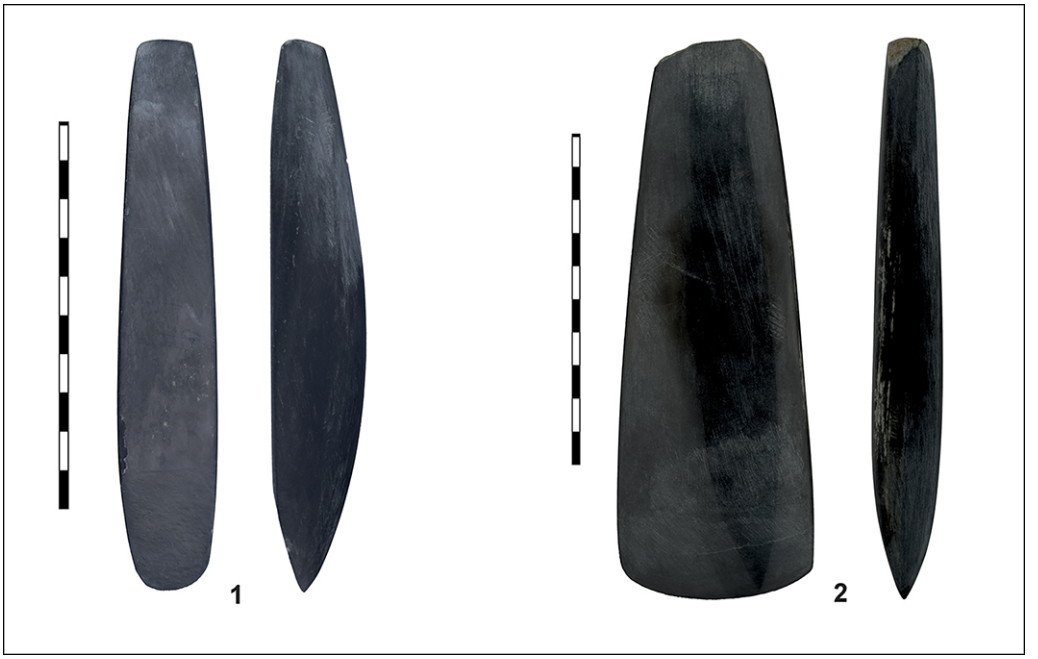


Figure 1. Main types of adzes from the Neolithic LBK: 1) the shoe-last celt; 2) the flat adze. Each scale is 100mm (©WEAR; figure by Laura Dietrich).

the design and everyday use of these tools remains limited. Bifacial hitting and cutting tools are dynamic, shape-transforming tools, subject to continuous morphological change throughout their use-life (Schiffer 1987). Nevertheless, conventional typological approaches in Central Europe have relied on static classification systems based on numerical ratios between dimensional parameters—such as length, width and thickness—which are typically assumed to be stable (e.g. the thickness-to-width ratios of Ramminger 2007). Previous investigations have combined typological analyses with provenance studies (e.g. Ramminger 2007) to delineate temporally and regionally distinct production types and to map tool distribution patterns across Europe. However, such taxonomic studies often rely on subjective morphological criteria (Schauer 2018) and selective documentation, such as contour drawings. In addition, use-wear traces on tool surfaces (Masclans *et al.* 2021) have been employed to infer function or to assess tool suitability for specific tasks (Elburg *et al.* 2015), but these analyses typically involve small datasets and qualitative assessments. Both research paradigms face interpretive constraints stemming from heterogeneity in data quality, variability in archaeological training and expertise, and the subjectivity inherent in perceptual shape analysis—factors that can lead to biased feature selection or overfitting of interpretations. Consequently, key challenges persist in developing comprehensive analytical approaches that meet current scientific standards of quantification, transparency and reproducibility (Marreiros *et al.* 2020).

To address these limitations, Project WEAR is developing an integrated methodological framework combining controlled experimental archaeology with computational

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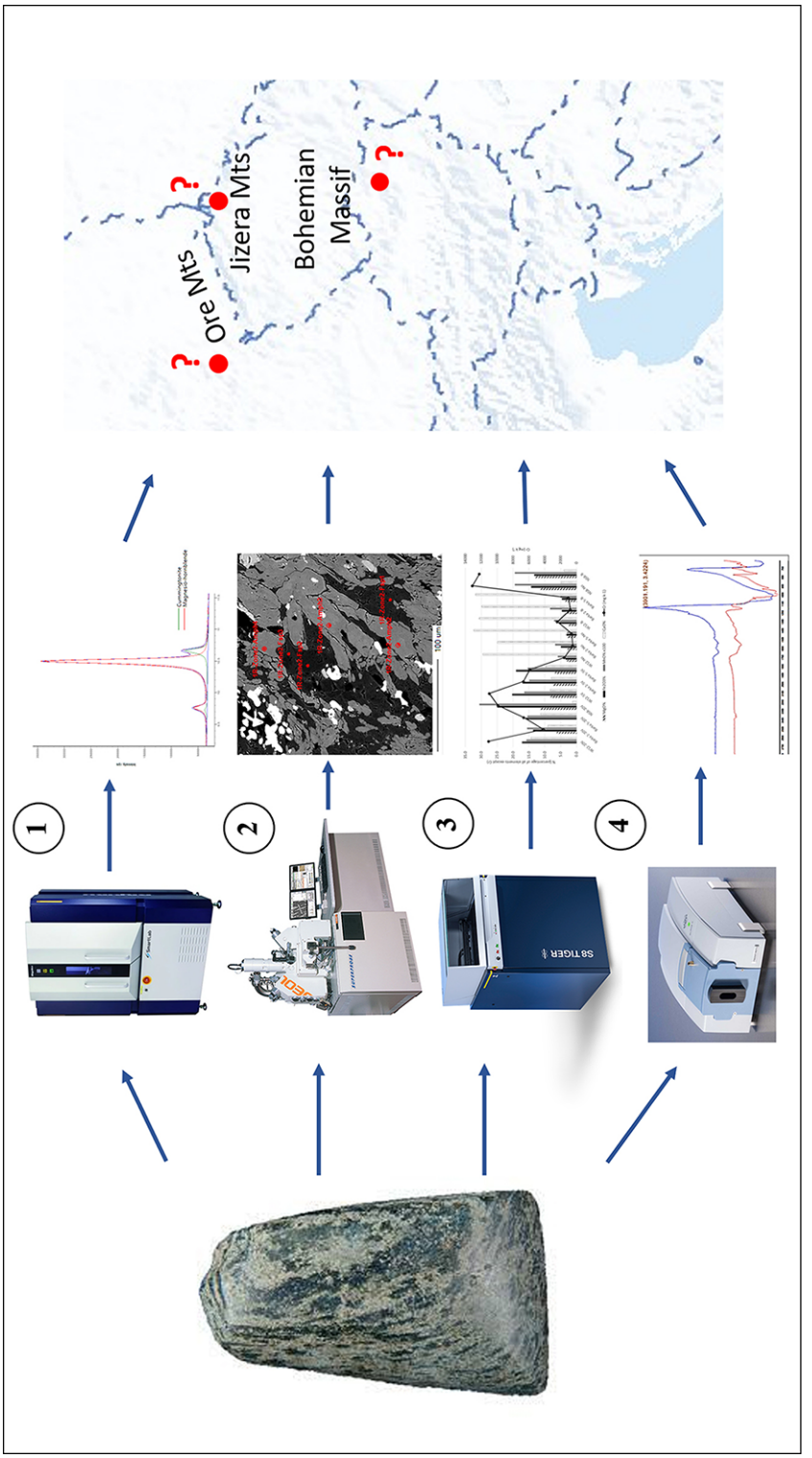


Figure 2. Analytical protocol for the characterisation and provenance determination of raw materials for Neolithic stone bifaces: 1) x-ray diffraction (XRD) identifies crystalline phases, determines amphibole unit-cell parameters and traces compositional changes; 2) electron probe microanalysis (EPMA) provides in situ major and minor element data, revealing zoning and compositional variations; 3) x-ray fluorescence (XRF) determines bulk major and trace element compositions; 4) fourier-transform infrared spectroscopy (FTIR) identifies structural differences that may support provenance analysis (©WEAR; figure by Iris Schmidt & Michael Brandl).

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modelling of use-induced morphological transformations. Its objectives are to quantitatively characterise and statistically explain variability in tool design and function, reconstruct the complete morphological and functional life histories of axes, adzes and chisels, and establish a reference dataset of 'wear states' representing possible preservation conditions of tools recovered from archaeological contexts.

Methods

Central to our approach is the use of small, empirically grounded datasets comprising representative tool 'types', which serve as reference anchors for the generation of larger, synthetic datasets. The open access datasets (available from the Wear Project Community; https://zenodo.org/communities/wear/) are developed within a framework of large-scale experimentation, guided by principles from synthetic engineering and constrained by biological and material parameters, and encompass detailed information regarding the properties of raw materials as well as the characteristics of tools and their uses, as inferred from experimental replication and not limited to the archaeological contextual evidence. The workflow includes the systematic selection of raw material variables (Figure 2), tool replication and long-term experimentation of use (Figure 3), and

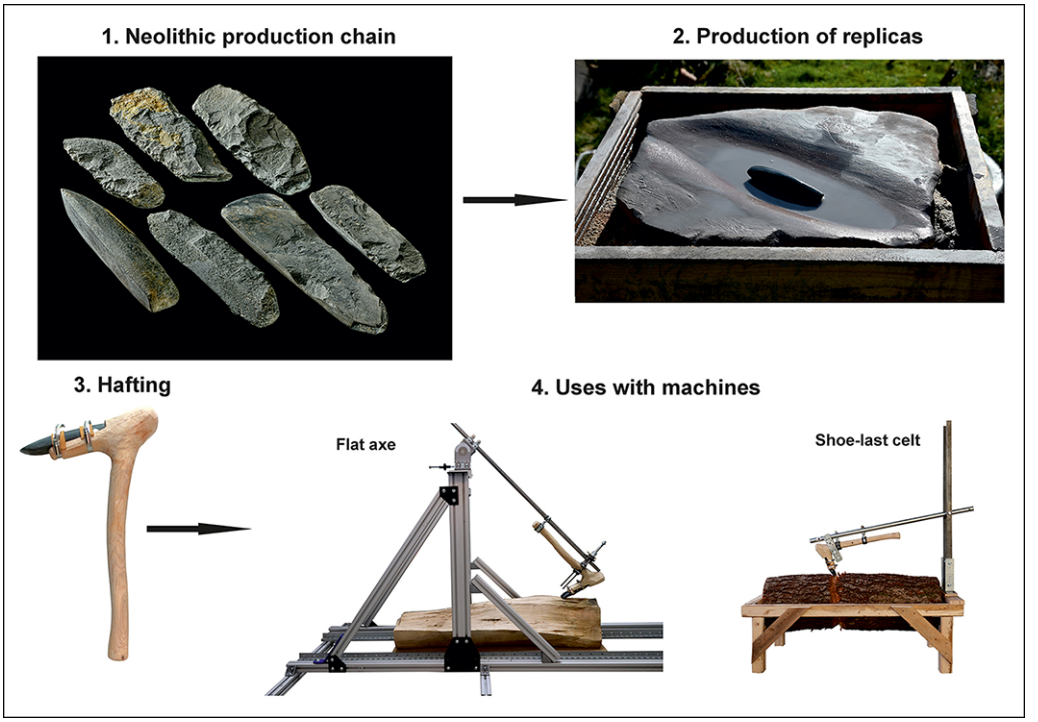


Figure 3. Analytical protocol for the experimentation (image 1: © LDA Sachsen-Anhalt, Juraj Lipták; images 2 & 3: © Wulf Hein; image 4: © WEAR, designed by Walter Gneisinger and Lohengrin Baunack, figures by Lohengrin Baunack).

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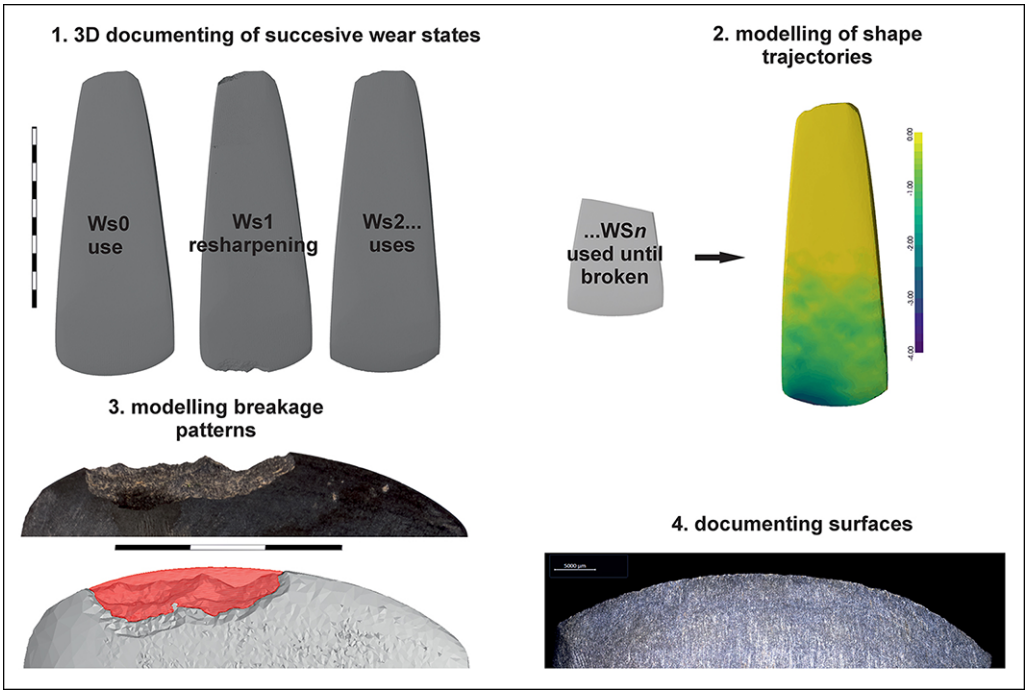


Figure 4. Analytical protocol for the documentation (©WEAR; 1 & 3 by Laura Dietrich; 4 by Marina Eguíluz Valentini; 2 by Christoph von Tycowicz).

structured three-dimensional shape documentation at fixed intervals (Figure 4, no. 1). This latter task includes mathematical modelling of shape transformations (Figure 4, no. 2) and the identification of wear and deformation patterns (Figure 4, nos. 3 & 4) that will permit the detection of signatures of original artefact use by leveraging synthetic data. The raw material variability is evaluated through stress tests (i.e. uniaxial compression, triaxial and tensile tests). Biological variability (e.g. motion, duration of work or intensity of the pressure) is controlled using machines (Figure 3, no. 4), while human participants serve as a comparative control group. The documentation includes protocols, 3D modelling in sequenced wear states and the computing of shape trajectories. For raw material characterisation and provenance determination, we analyse the mineralogical and geochemical properties of the original tools using x-ray diffraction, electron beam microprobe analysis, x-ray fluorescence analysis and Fourier transform infrared spectroscopy (Figure 2). The shape trajectories capturing the wear progression are estimated from the experimental series using a regression approach (Figure 5). To account for the non-linearity in shape changes, we regress a geodesic parametric model (Hanik *et al.* 2024) against tool surfaces represented in size-and-shape space. Geometric group tests allow us to identify systematic differences in the distributions of shape trajectories between machines/robots and human experimental executors.

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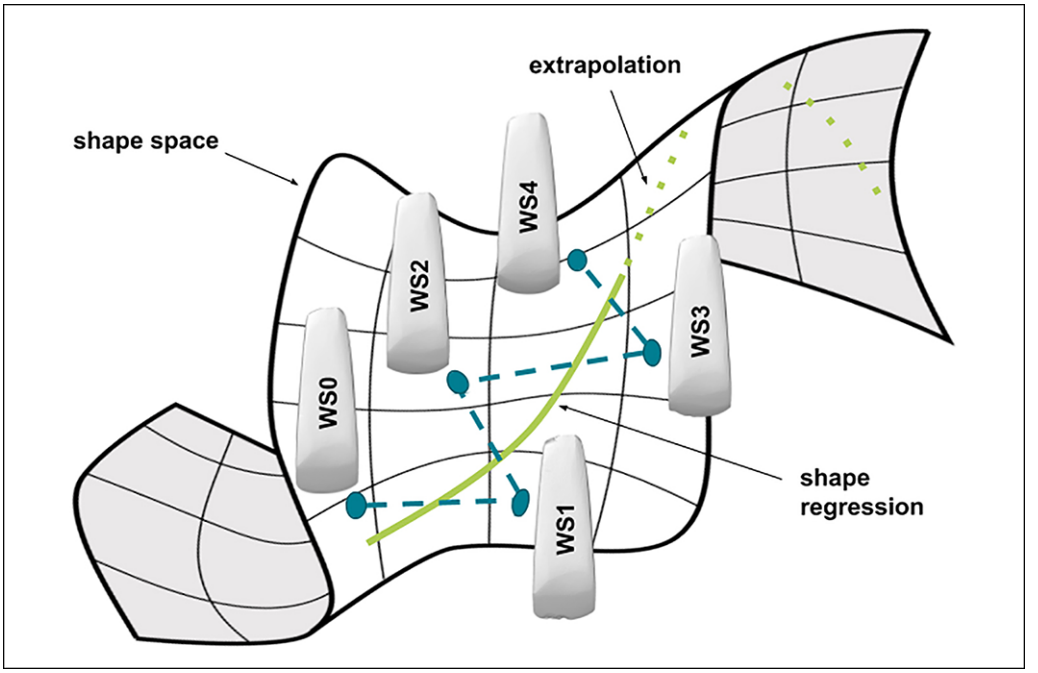


Figure 5. Representation of form trajectories in form spaces (© WEAR; figure by Julius Mayer, Christoph von Tycowicz, Laura Dietrich and Lohengrin Baunack).

Results

Our data, derived from experimental replication and shape trajectory analysis, indicate that size and other wear parameters change concurrently—though at disproportionate rates—during successive episodes of use and resharpening of the tools (Figure 4, nos. 1, 2; Figures 5 & 6). As such, metric ratios should not be treated as fixed or invariant. This is particularly relevant given that archaeological measurements are generally taken at arbitrary stages of tool wear and preservation. Consequently, each archaeologically recovered artefact assigned to a typological cluster represents a distinct point (or 'wear state') along a continuum of morphological transformation, shaped by its individual history of use, maintenance and depositional context.

In the case of the flat adzes—our focus here—a scatter plot (Figure 6; supplementary table on https://zenodo.org/communities/wear/records) of the length and width of 336 preforms (orange) and finished or used tools (blue) from settlements, cemeteries and hoards of the LBK reveals a continuous distribution within a single cluster, with sample density decreasing as length increases. The preforms are among the longest examples, suggesting long use-lives and indicating that the observed variability in design and 'types' in archaeological contexts is more plausibly explained by intensity of use and task variation rather than by stylistic or technological choices.

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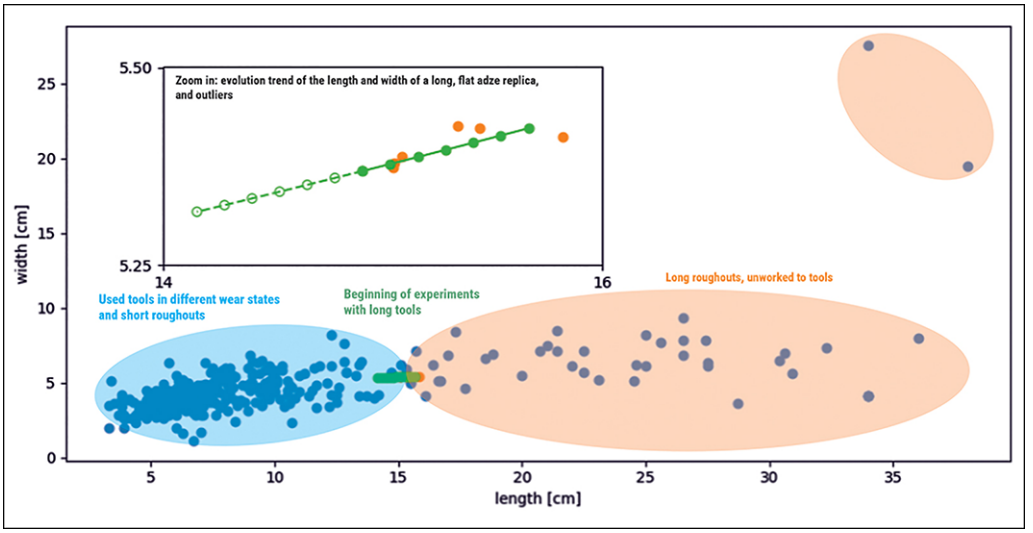


Figure 6. Plot of the lengths and widths of 336 complete preserved flat adzes from Central Europe and of experimental wear states (© WEAR; figure by Julius Mayer and Laura Dietrich).

The integration of synthetic data—encompassing metrics such as working time, characteristic breakage patterns (Figure 4, no. 3) and task-specific wear—enables identification of original tool function and transformation across long-duration use processes by quantitatively fitting replica size and wear profiles to the archaeological record. The variation in the shapes of the analysed flat adzes is likely the result of a single 'prototype' design, probably considered highly efficient for carpentry work.

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Online supplementary material (OSM)

To view supplementary material for this article, please visit the Zenodo data repository at https://zenodo.org/communities/wear/records

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