Woodworking and carpentry skills of the first agricultural societies in central Europe

Le travail du bois des premières sociétés agricoles d'Europe centrale

Bernhard Muigg[1,2,] Rengert Elburg[3], Wulf Hein[4], Anja Probst-Böhm[5], Sebastian Böhm[6], Peter Walter[7] and Willy Tegel[2]

[1] Chair of Forest History, Institute of Forest Sciences, University of Freiburg, D-79106 Freiburg, Germany – muigg@dendroarchaeology.com
[2] Amt für Archäologie, Kanton Thurgau, CH-8510 Frauenfeld, Switzerland
[3] flintsource.net
[4] Arc-Tech GbR, Büdinger Str. 1, D-63633 Birstein, Germany
[5] Archäologisches Landesmuseum Baden-Württemberg, D-78467 Konstanz, Germany
[6] Institute for Prehistory and Protohistory, Friedrich-Alexander-University Erlangen-Nürnberg, D-91054 Erlangen, Germany
[7] Pfahlbaumuseum Unteruhldingen, D-88690 Uhldingen-Mühlhofen, Germany

***In memoriam* Manfred Keller**

ABSTRACT. The process of Neolithization reached central Europe in the 6th millennium BCE. During this time, first considerable human impact on natural vegetation occurred and the development of sedentary lifestyles in permanent settlements, agriculture and livestock breeding imposed novel requirements on local woodlands. At the same time, the intensive use of wood led to significant innovations and advances in woodworking techniques. Here, we present an overview of the latest results of our investigation of Early Neolithic woodworking in Europe. Several water wells with preserved wooden linings from the Linear Pottery Culture (LBK; ca. 5500-4800 BCE) have been excavated within the last two decades and allow detailed insight into the advanced carpentry skills. Following a multidisciplinary approach, dendroarchaeological and experimental studies are combined to provide a comprehensive overview of woodworking methods, tools, and thoughts on resource exploitation. Additionally, a possible *chaîne opératoire* is discussed. The almost exclusive use of oak (*Quercus* sp.) for rectangular well linings points towards deliberate species selection, implying expert knowledge of mechanical properties of wood, also demonstrated by elaborate splitting techniques. The use of specialized tools for specific tasks indicates a high level of specialization in woodworking. Different joint types illustrate the technical variety and sophisticated nature of Early Neolithic carpentry.

RÉSUMÉ. Le processus de néolithisation a atteint l'Europe centrale au VIe millénaire avant notre ère. À cette époque, il est possible, pour la première fois, de prendre en considération l'impact des sociétés humaines sur la végétation naturelle. La sédentarisation, l'agriculture et l'élevage ont imposé de nouvelles exigences aux forêts locales. Dans le même temps, l'utilisation intensive du bois a donné lieu à d'importantes innovations et avancées techniques concernant le travail du bois. Nous présentons ici un aperçu des derniers résultats de notre étude sur le travail du bois au Néolithique ancien. Plusieurs puits de la culture rubanée (ou culture à céramique linéaire, ou plus simplement le Rubané ; en allemand *Linienbandkeramische Kultur* ou *Linearbandkeramik*, abrégé en LBK), dont les parois ont des revêtements en bois encore préservés, ont été fouillés au cours des deux dernières décennies et offrent un aperçu détaillé des compétences avancées en matière de menuiserie. En suivant une approche multidisciplinaire, des études dendroarchéologiques et expérimentales sont combinées pour fournir un aperçu complet des méthodes de travail du bois, des outils et des réflexions sur l'exploitation des ressources. En outre, une possible chaîne opératoire est discutée. L'utilisation presque exclusive du chêne (*Quercus* sp.) pour les revêtements de puits à section quadrangulaire indique une sélection délibérée de l'espèce, impliquant une connaissance experte des propriétés mécaniques du bois, également démontrée par des techniques de fendage élaborées. L'utilisation d'outils spécialisés pour des tâches spécifiques indique un haut niveau de spécialisation dans le travail du bois. Les différents types de joints illustrent la variété technique et la nature sophistiquée de la menuiserie du Néolithique ancien.

KEYWORDS. Early Neolithic, Woodworking, Dendroarchaeology, Water wells, Experimental Archaeology.
MOTS-CLÉS. Néolithique ancien, Travail du bois, Dendroarchéologie, Puits d'eau, Archéologie expérimentale.

Introduction

During the middle of the 6th mill. BCE, the first agricultural societies established themselves in central Europe, marking the onset of the Neolithization in this region (Price, 2000; Shennan, 2018). The transition in lifestyle from mobile hunter-gatherers of the Mesolithic period to sedentary Neolithic societies was accompanied by new challenges of clearing forests and cultivating arable lands in predominantly forested central Europe. Changing requirements of permanent settlements were imposed on local woodlands, leading both to the first considerable human impact on natural vegetation and to significant advances in woodworking techniques (Lüning, 2005; Tegel *et al.*, 2012). Based on the characteristic pottery decoration style, archaeologists refer to the first Early Neolithic farmer's societies in central Europe as the Linear Pottery Culture (LBK, from German: *Linearbandkeramik*), dating roughly to the second half of the 6th mill. BCE (Lüning, 2005; cf. Manning *et al.*, 2014). The spread of LBK culture oriented along the large river valleys and quickly extended on the fertile loess soils (Tegel *et al.*, 2012; Czekaj-Zastawny, 2017). The structures of LBK settlements are very similar across Europe, suggesting a subsistence economic system of combined agriculture and animal husbandry (Lüning, 2005). From the uniform architecture, characterized by longhouses with floor plans often over 30 m in length, it is assumed that the first farmers lived in larger groups (Price, 2000; Stäuble, 2005).

The longhouses and most other wooden structures from the period have vanished due to biodegradation and can only be investigated on the basis of soil discolorations in archaeological features (e.g. postholes), which provides an idea of size and shape of timber constructions but does not allow to recognise woodworking details (Stäuble & Wolfram, 2012). Under waterlogged conditions, however, wooden remains can be preserved for millennia (Tegel *et al.*, 2022). Water wells provide such preferable conditions and are occasionally found in LBK settlements as essential structures for securing the water supply (Vostrovská *et al.*, 2021). Several water wells with preserved wooden linings have been excavated within the last two decades and allow detailed insight into the advanced carpentry skills of the LBK period in central Europe (***figure 1***).

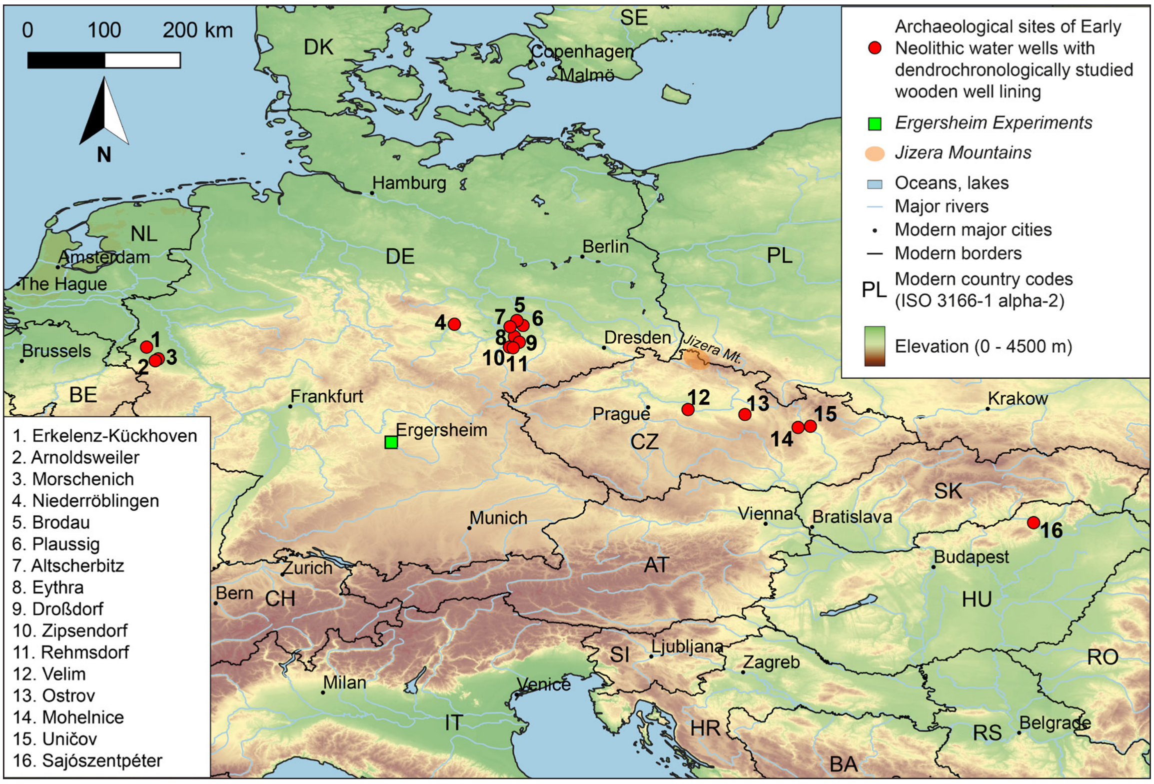

Figure 1. *Archaeological sites of Early Neolithic water well constructions with preserved and dendrochronologically studied wooden linings. Map based on Tegel* et al. *(2012, cf. Elburg, 2011, figure 1), supplemented with more recent excavations (9: Kretschmer* et al.*, 2016; 12 and 15: Rybníček* et al.*, 2018; 13: Rybníček* et al.*, 2020; 16: Király & Tóth, 2015). For an up-to-date list of LBK structures interpreted as water wells (also without wood preservation) see Vostrovská* et al.*, 2021, fig. 1. © B. Muigg.*

In this paper, we present an overview of the latest results from a multidisciplinary approach, combining dendroarchaeological and experimental studies on Early Neolithic woodworking.

1. Material and methods

So far, about 100 Early Neolithic water wells have been excavated from 53 sites in Europe, spreading from north-eastern France to north-eastern Hungary (Vostrovská *et al*., 2021, figure 1). Not in all cases the wooden structures were preserved or documented. However, the examples with preserved wooden lining from 16 archaeological sites in central Europe (***figure 1***) provide detailed information on the construction and allow to distinguish different designs, technical solutions, and static concepts of Early Neolithic water wells (***figure 2***).

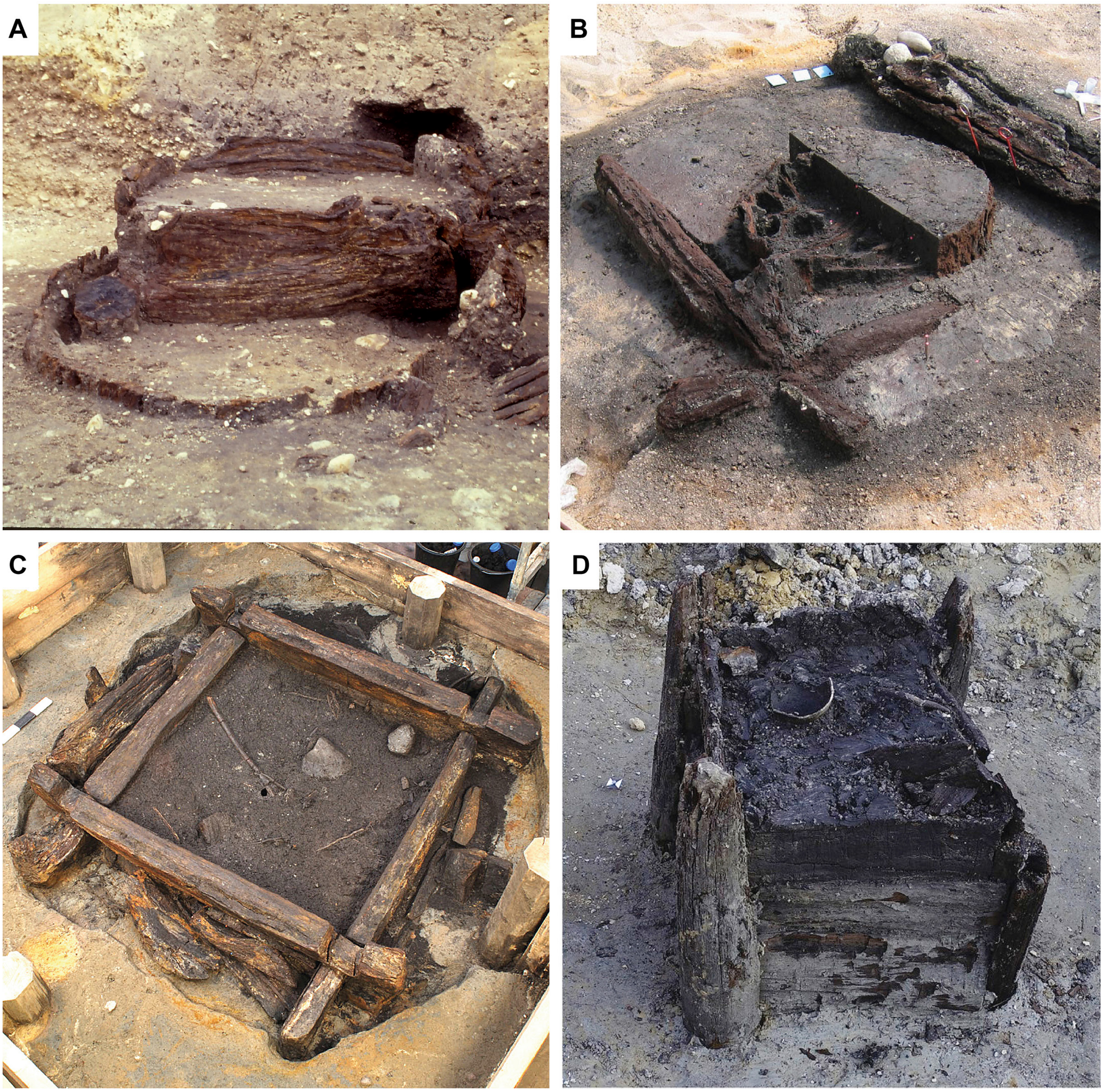

Figure 2. *Different construction types known from early Neolithic water wells. A. wickerwork structure from Eythra, DE; B. hollow trunk from Brodau, DE (combined with type C well); C. « blockbau » construction from Altscherbitz, DE; D. posts-and-planks construction from Ostrov, CZ. © B. Muigg, based on Tegel* et al.*, 2012, Fig. 1B-D and Rybníček* et al.*, 2020.*

Large amounts of stone tools from LBK contexts published from numerous excavation sites in central Europe provide a vast inventory for replicas for practical experiments on Early Neolithic woodworking (e.g. Weiner, 1996, with further references). Typical LBK woodworking tools are made from different polished stones (***figure 3a, b***) and display a characteristically pronounced asymmetrical shape with a domed upper side and a flat bottom with a distinct bevel towards the cutting edge, clearly indicating a hafting as adzes, with the cutting edge perpendicular to the handle instead of parallel as with axes (Weiner & Pawlik, 1995; Elburg *et al*., 2015). Therefore, adzes have to be regarded as the typical LBK woodworking tools, appearing in various sizes and weights and thus, suggesting different functions and areas of application (Ramminger, 2007; Elburg *et al*., 2015). Ramminger (2007) distinguishes four typological categories, based on the absolute width of the blade and a height-breadth-Index (HBI), calculated by dividing the thickness of the blade by its breadth, multiplied by 100 (***figure 3c***). Flat blades (type 2) with a height-breadth-index (HBI) of less than 50 (i.e., height less than half the breadth) are the most common type. In contrast, type 3 is defined by a HBI between 50 and 100 and therefore includes medium high blades. Adzes of type 4 (HBI >100) are high and mostly quite narrow (between 30 and 40 mm), whereas type 1 blades are characterized by a width less than 20 mm (Ramminger, 2007). With regard to woodworking purposes, these four types suggest different specialised functions. Other artefacts interpreted as tools for woodworking were made from bone and antler (Weiner, 1996; Domboróczki, 1997; Fehlmann, 2010).

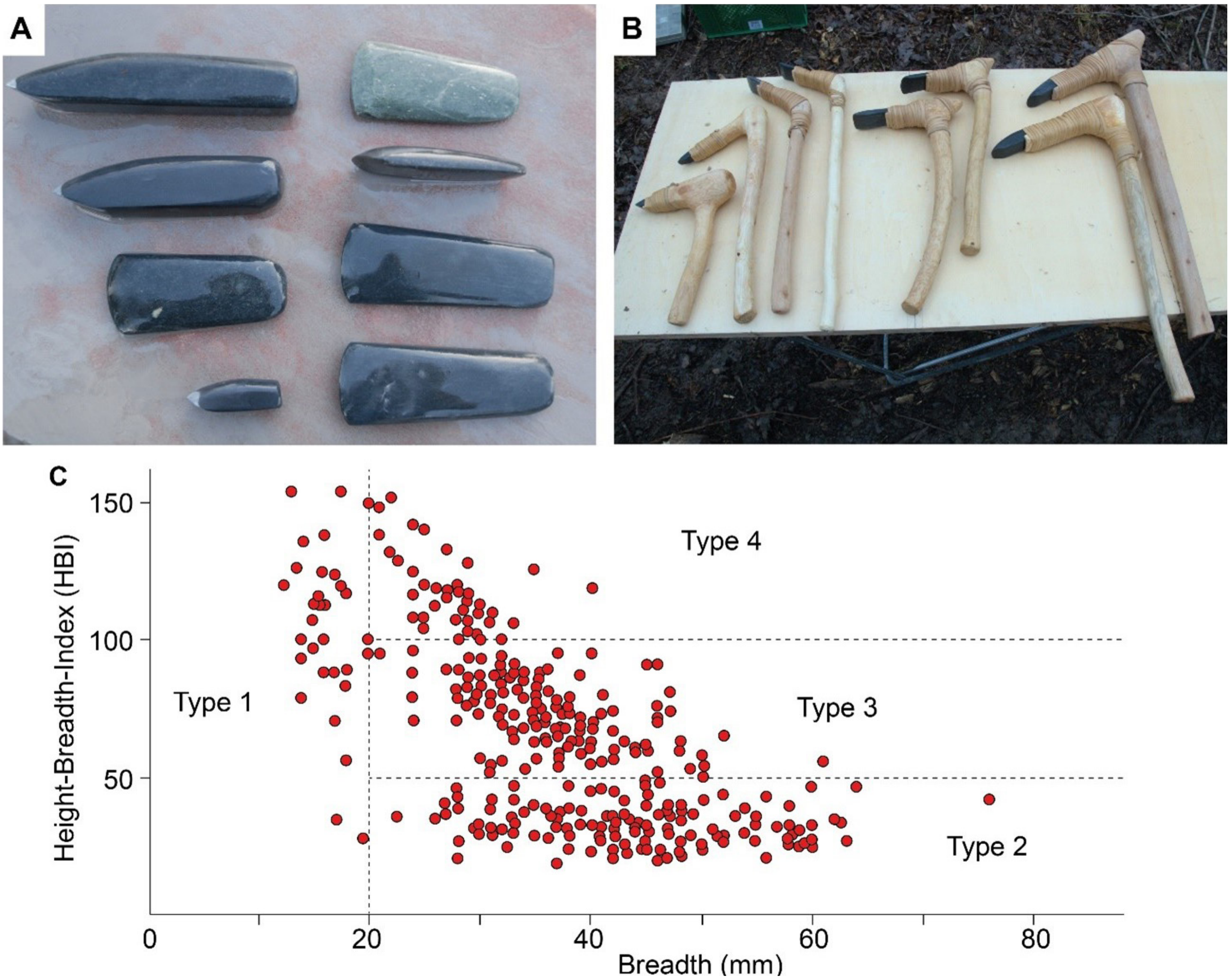

Figure 3. *Collection of replica of early Neolithic polished stone tools produced by Wulf Hein (A) and hafted on different handles (B) as well as typological classification (C) of LBK adzes according to Ramminger (2007). © B. Muigg, based on photos by W. Hein and on Elburg* et al. *2015, fig. 2.*

1.1. Dendroarchaeology

Ideally, timber remains of Early Neolithic well linings are studied with dendroarchaeological methods immediately after the excavation. This way it is possible to study the original surface of the freshly excavated wooden objects for tool marks (***figure 4a, b***). In recent decades, several water wells have been block-lifted with the surrounding soil and excavated under optimal indoor conditions, which on the one hand reduced the time pressure for the excavating archaeologists and on the other hand, enabled dendroaechaeological analyses parallel to the excavations (Elburg, 2010a; Tegel *et al*., 2012; Kretschmer *et al*., 2016; Schell & Herbig, 2018).

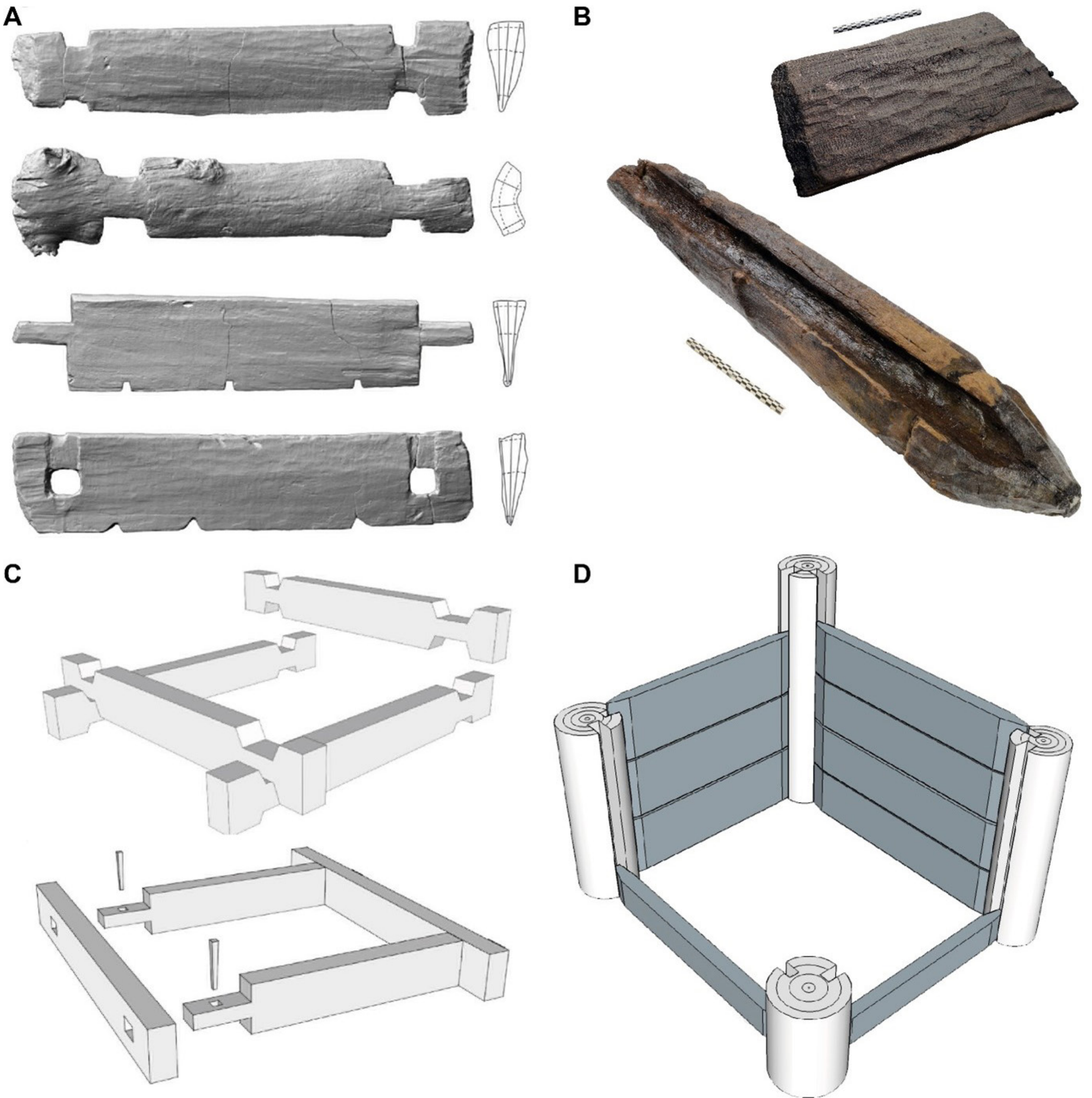

Figure 4. *Constructive solutions and timber joints for well types C and D. Left (A and C): The « blockbau » constructions from Altscherbitz, DE, shows corner joints with recesses on both sides and mortice-and-tenon joints as well as a pin lock in the basal frame (C; bottom). Right (B and D): The type-D well from in Uničov, CZ, displays longitudinal grooves in the corner posts and tapered end grain on the inserted planks for tongue-and-groove connections. © B. Muigg, based on Tegel* et al.*, 2012, Fig. 4B-D, Rybníček* et al.*, 2018, fig. 2A, 2020, fig. 2B and on photos by B. Muigg and W. Tegel.*

Standard dendroarchaeological studies comprise documentation, taxonomical identification, and dendrochronological analyses. The investigation of the object surface provides information on surface treatment and tool marks, documented by sketch drawings and photography. Novel techniques of archaeological on-site documentation and post-excavation treatment (e.g. high-resolution 3D-laserscanning) provide new possibilities to reconstruct excavated features in their original distribution and interconnection (***figure 4a***) and further intensify the study of tool marks and traces of wear (Tegel *et al*., 2012; Elburg *et al*., 2014).

Taxonomical identification of tree species is performed on transverse, radial and tangential thin sections under transmitted light microscopes. Timbers originating from the well linings, construction pits and well infills are selected for dendrochronological analyses. To improve dating results and precision, the timber sections suitable for sampling are selected by a sufficient number of tree rings and preferably featuring wane and pith. Zones showing growth anomalies are generally avoided. Cross-sectional samples are cut from the individual timbers to measure their tree-ring widths to an accuracy of 1/100 mm, using stereo microscopes, semi-automatic measuring systems and the software PAST4 by SCIEM (http://www.sciem.com; Tegel *et al*., 2022). Before the dendrochronological analyses, sample surfaces are prepared with razorblades to facilitate the microscopic tree-ring measurement, and occasionally treated with chalk powder to improve the visibility of tree-ring borders. In addition, the timber cross-sections are drawn to scale, indicating the course of the tree-rings and other wood anatomical features to enable fast information gain on the position of a wooden object within the stem and possible technical details (e.g. longitudinal division of timber by splitting). The recorded parameters include the form and shape of the object, information on cross-section, tool marks and other surface treatments, taxon, the number of tree rings, where possible, dendrochronological dating, and other wood anatomical features like pith, wane, and sapwood proportion.

1.2. Experimental Archaeology

The field of Experimental Archaeology subjects the practical implementation of theoretical hypotheses in experimental test series and thus, provides important information for further explanation models (Mathieu, 2002). As demonstrated above, the archaeological record points towards an exclusive use of adzes for the LBK period. Hardly any experimental work involving adzes had been carried out before the onset of the *Ergersheim Experiments*, a joined project of experimental Archaeologists on Early Neolithic woodworking techniques, initiated in 2011 (Elburg & Hein, 2011; Walter *et al*., 2012). Therefore, the experimental approach started with quite fundamental questions and initial hypotheses, concerning the suitability of stone adzes for felling oaks with large diameters (> 50 cm), possible hafting of polished stone blades, cutting techniques and the comparison of produced tool marks with the ones on original wooden objects (Elburg *et al*., 2015).

To address these questions, experiments were carried out with a number of tool replicas of all four abovementioned blade types (***figure 3a***), manufactured mostly from erratic stones from the Baltic Sea, presumably a type of diabase, and of actinolite-hornblende schist from the Jizera Mountains in Eastern Bohemia (***figure 1***), the most widely used raw material for polished stone tools in the LBK (Přichystal, 2013). All blade replicas were thoroughly documented with detailed micro-photos of the cutting edges and high-resolution 3D-laser scans for future use-wear studies (Elburg *et al*., 2015). As preserved wooden handles from the LBK are extremely rare (Elburg, 2008), archaeological finds from later Neolithic periods (Müller-Beck, 1965) as well as analogies from ethnographical sources and ergological considerations had to be included for the question of hafting (Pétrequin & Pétrequin, 1993). Twentieth century haftings from New Guinea ranged between 46° and 88°, with an average angle around 62° (Blackwood, 1950) and 70° (Godelier & Garanger, 1973), respectively. After first experiences in practical tests in 2011, lashings for the blades were made with rawhide and the angles for heavy blades were adjusted between 70° and 80° (***figure 3b***; Elburg *et al*., 2015). A special form of hafting with an obtuse angle of ca. 115° was replicated after shaft remains from Altscherbitz, DE

(Elburg, 2008). First felling experiments were carried out in 2011 and 2012 (Elburg & Hein, 2011; Walter *et al*., 2012). The felling process was documented by photo and film (https://www.ergersheimer-experimente.de/index.php/en/publications) and the development of the felling notches was additionally recorded tachymetrically and from 2014 with a portable Artec EVA 3D-scanner (Elburg *et al*., 2015). For the further processing of the felled oaks, large hardwood wedges were used for splitting, based on find from later Neolithic periods (e.g. de Capitani *et al*., 2002). Bone and antler tools are known from different LBK sites (e.g. Fehlmann, 2010). Massive bone chisels made of metatarsals of cow-sized animals, as found for example in Müddersheim, North Rhine-Westphalia, DE (Schietzel, 1965), and other tools of bone and antler have been replicated. All experiments took place in traditionally managed oak-dominated coppice-with-standards forests close to the village of Ergersheim, Bavaria, DE (***figure 1***). The available oaks had diameters ranging from 25 to 55 cm and individual tree ages between approximately 90 to 120 years (Elburg *et al*., 2015).

2. Results

2.1. Early Neolithic water well architecture

Four different construction types of LBK water wells could be distinguished from the archaeological record (***figure 2***).

Type A are wickerwork well shafts that served primarily to prevent the contamination of the water by falling sediment from the pit walls. An archaeological feature (n. 3650) from Droßdorf, Saxony, DE, provides an LBK-period example for type A, dendrochronologically dated to 5143 BCE (*terminus post quem*) (Kretschmer *et al*., 2016).

Type B are hollowed-out trunks, forming a tube-shaped lining. Examples for this well type are known, *inter alia*, from Eythra, DE, Sajószentpéter, HU, Droßdorf, DE, and Velim, CZ (Tegel *et al*., 2012; Király & Tóth, 2015; Kretschmer *et al*., 2016; Rybníček *et al*., 2018).

Type C, known to archaeologists for the LBK period for several decades (e.g. Weiner, 1991, 1998b; Stäuble & Campen, 1998), is the classic « *blockbau* » construction. First experimental archaeology work on this construction type was performed by Lobisser (1999). With novel finds from the more recent excavations, for example in Altscherbitz, Saxony, DE (Elburg, 2010a; Tegel *et al*., 2012), further archaeological experiments were carried out during the *Ergersheim Experiments* (Elburg *et al*., 2015).

Type D, characterized by the combined use of longitudinally grooved corner posts with inserted horizontal boards or planks, has only recently become known for the LBK period with the discoveries of such wells 2016 in Uničov, CZ, and 2018 in Ostrov, CZ, (Rybníček *et al*., 2018, 2020; Vostrovská *et al*., 2020, 2021). In contrast to type C, where the statically stable « *blockbau* » consisted of horizontal planks, interconnected with corner joints, type D formed the static framework with different vertical and horizontal components and thus, demonstrates a significantly different structural concept. First experiments on type D wells were carried out by the authors at the *Ergersheim Experiments* 2019 and will be continued after a corona-induced pause in the next years.

2.2. Anthropogenic selection of species and individual tree ages

Dendroarchaeological investigations on type A water wells were largely restricted to microscopic identification of the used wood species due to the low number of tree rings in the wickerwork. For the structure n. 3650 from Droßdorf, DE, the exclusive use of young oaks (*Quercus* sp.) with less than 20 tree rings was established for both, roundwood stakes and wickerwork (Kretschmer *et al*., 2016). Thus, dendrochronological dating to the LBK period was only possible due to a fragmented splitwood plank from the infill. The diameter for type B wells is limited to the trunk size. Hence, this type required large stem diameters and thus, mature trees. In Droßdorf, DE, diameters around 70 cm have been recorded for maple (*Acer* sp.) trunks (Kretschmer *et al*., 2016), the oak trunks from Mohelnice, CZ, and Sajószentpéter, HU, showed diameters of 65 cm and 90 cm, respectively (Opravil, 1972; Király & Tóth, 2015). Individual tree age could not be obtained, as the inner parts of the trunk had been removed. Despite the low number of published species determinations for tube-like wells (n=6), taxonomical identifications indicate a tendency for the preference of maple, making up 50 % of the securely identified type B wells (in Droßdorf, DE, feature n. 3648 and 3678; Kretschmer *et al*., 2016; Eythra, DE, Tegel *et al*., 2012), besides 33.3 % oak, identified in Mohelnice, CZ, (Opravil, 1972) and Sajószentpéter, HU, (Király & Tóth, 2015) and 16.7 % lime (*Tilia* sp.) in Velim, CZ, (Rybníček *et al*., 2018). In contrast, the rectangular well linings of types C and D were exclusively made from oak that provides tough and durable wood, relatively easy to split (Wagenführ, 2000; Grabner, 2017). For type C, some examples demonstrate the use of roundwood logs from young oaks (e.g. in Droßdorf, DE, n. 3619, < 20 years; Kretschmer *et al*., 2016). The vast majority of type C wells, however, were constructed using split planks manufactured from mature oaks with individual tree ages of up to approximately 300 years and large stem diameters up to 1 m (Weiner, 1998a; Tegel *et al*., 2012; Kretschmer *et al*., 2016). For type D, the use of two different tree age classes could be documented: younger roundwood logs with less than 100 years were used for the corner posts (ages of ca. 35 years in Uničov, CZ, and ages of 33-82 years in Ostrov, CZ), whereas the inserted boards and planks show up to 190 tree rings and thus, indicate mature oaks (> 100 years) with diameters of at least 50 cm for Uničov and 60 cm for Ostrov, respectively (Rybníček *et al*., 2018, 2020). In several cases for types C and D, extraordinary high similarities in the growth of some individual planks within one well construction allowed to attribute them to the same tree (e.g. Tegel *et al*., 2012; Rybníček *et al*., 2018, 2020), which further supports the use of greenwood, installed immediately after processing splitwood planks.

2.3. Timber joints and carpentry

Archaeologically excavated well linings show a variety of different techniques for connecting wooden parts. The wickerwork of type A wells combines vertical stakes with small-dimensioned horizontal twigs, making use of their mechanical flexibility. In the type B well from Sajószentpéter, HU, individual trunk segments were connected with laces made of small branches (Király & Tóth, 2015). While types A and B did not require actual timber joints, types C and D provide evidence for sophisticated carpentry of the LBK people. The « *blockbau* » constructions of type C show corner joints with recesses on one or both sides (***figure 4a, c top***), interlocking the planks of the construction. Type D wells display tongue-and-groove connections between the corner posts and the inserted planks (***figure 4b, d***). The basal frame of the type C water well from Altscherbitz, DE, was connected with mortice-and-tenon joints (***figure 4a, c bottom***; Tegel *et al*., 2012) and furthermore provided evidence for the oldest pin lock of the world (Elburg, 2010b). These results demonstrate that LBK carpenters were familiar with the most important basic timber joints.

2.4. Woodworking process

Dendroarchaeologically documented splitting techniques predominantly show radial splitting and occasional tangentially split planks (Tegel *et al*., 2012; Rybníček *et al*., 2018, 2020). Both processes also could be successfully reconstructed by experimental archaeology (***figure 5***; Elburg *et al*., 2015). Different tool marks documented on the original timbers could be attributed to specific types of stone blades (***figure 6***): Type 2 adze blades were used for smoothing of the split surfaces (***figure 6a, b***). The end grain of boards and planks (***figure 6a, c***) was predominantly worked with narrow blades of types 1 and 4, which have also proven most effective by the experimental work (Elburg *et al*., 2015). Practical considerations further suggest that cutting-to-length was performed after the splitting of boards and planks. Based on the shaft remains from Altscherbitz, DE (Elburg, 2008), adzes hafted with obtuse angles (up to 115°) were additionally tested (***figure 6b***) and proved to be efficient for reworking or smoothing the split surfaces (Elburg *et al*., 2015). Different tools were tested for cutting the recesses

Figure 5. *Experimental reconstruction of longitudinal splitting of oaks at the Ergersheim Experiments with wooden wedges of different sizes (A). Both radial (C) and tangential (B; D) splitting were successfully reproduced. © B. Muigg based on photos by B. Muigg, S. Böhm, R. Elburg, W. Hein, A. Probst-Böhm and P. Walter.*

for Type C wells and the mortices for the Altscherbitz basal frame (Elburg *et al*., 2015). All adzes performed poorly, as their relatively blunt edges make it almost impossible to work perpendicular to the wood fibres. The angle of the wooden handle limits the working angle and the adze hafting furthermore restricts the possible working depth to the length of the blade protruding from the haft. Best results for producing such timber joints were obtained with bone chisels (***figure 6d, e***). The produced toolmarks closely resemble the traces on the joints of the original wood lining (Elburg *et al*., 2015), strongly suggesting the use of bone chisels for by LBK carpenters. First experiments on the grooves of the type D wells did not finally clarify which tools were used. Both type 4 adzes and bone chisels are possibly suitable for this work, as are stone gouges (Walter, 2021), which need to be compared for their working traces in future experiments.

3. Discussion

The overall corpus of archaeological sites of LBK water wells with preserved wooden linings (***figure 1***) is still too small to address questions of the chronological and geographical changes in shape or building techniques. Nevertheless, new archaeological finds from recent years allowed to establish a basic typology of LBK water wells, which includes four types of wooden structures, distinguished by their different constructive and static concepts. The common features of all types are a large and deep pit, providing permanent waterlogged conditions and, as a consequence, the preservation of wooden

Figure 6. *Experimental reproduction of tool marks observed and documented on the original woods with the help of high-resolution 3D laser scanning (A). Specific tool marks for processes could be addressed to different tools and processes, for example type 2 adze blades for smoothing splitwood surfaces (B), or narrow blades (type 1 and 4) for working the end grain (C). For other woodworking processes, stone adzes have proven less effective in the experiments, suggesting the use of bone chisels for producing timber joints like recesses (D) and mortices (E). © B. Muigg based on photos by B. Muigg, S. Böhm, R. Elburg, W. Hein, A. Probst-Böhm and P. Walter and on Tegel* et al*. 2012, Fig. 4A.*

elements. This suggests a context of water supply but does not necessarily indicate the function of a (fresh) water well (Elburg, 2011; cf. Weiner, 1998b). Especially for type A wells, where the lining was built of wickerwork with little static significance, other uses of water supply than drinking water could be possible, e.g. livestock watering or retting of bast or fibre plants. An example for the use of such plant material is provided by a large piece of folded bast, disposed in the construction pit of the type B well n. 3678 from Droßdorf, DE (Kretschmer *et al*., 2016, figure 23). Little is known about the woodworking process of type B wells due to largely bad preservation conditions and highly fragmented trunks. The inner parts had been removed, the remaining well shaft was only 3 cm thick in the example from Velim, CZ (Rybniček *et al*., 2018). So far, it has not been clarified whether core-rotten logs were deliberately used for the tube wells and how the interior was worked. Possible techniques are the use of fire, which has not yet been confirmed on dendroarchaeological material from the LBK, and tools made from stone, bone, or antler, as suggested by several examples with tool marks on the inner surface (e.g. Rybniček *et al*., 2018), or a combination of both. There is also evidence for the division of the tube in several boards (e.g. from Sajószentpéter, HU; Király & Tóth, 2015), which might have significantly facilitated the working process. The hollowing-out of large trunks might have been approached differently, most probably also using trunks hollow by nature (e.g. Ranius *et al*., 2009). No type B well is preserved in full length. Based on the depth of other well types, tubes of several meters are to be considered, which raises questions about the manufacturing process that need to be addressed in future experiments. Types A and B did not require sophisticated carpentry. In contrast, types C and D, representing two different basic constructive types of rectangular well linings, clearly demonstrate the carpentry skills of the LBK people. The exclusive use of oaks for timber in rectangular well lining constructions of type C and D shows a clear anthropogenic selection of a species suitable for such purposes and thus, sophisticated mechanical knowledge (Tegel *et al*., 2012; Grabner, 2017).

Based on the dendrological characteristics and observed tool marks on the original timbers and the practical results from experimental archaeology it is possible to discuss the chronological sequence of the working process and thus, provide the basic steps of a possible *chaîne opératoire* for construction of LBK water wells (***table 1***). The methodological concept of *chaînes opératoires* has been developed in the 1970s, mainly for palaeolithic stone tool production (Soressi & Geneste, 2011) but, on the foundation of a growing data basis of LBK wooden structures, can also be applied on woodworking processes.

Table 1. *Possible chaîne opératoire for Early Neolithic water well construction (types C and D) based on observations of tool marks on the original woods as well as dendroarchaeological and experimental considerations. © B. Muigg.*

<table>
<tr><th colspan="4">Probable course of woodworking (chaîne opératoire) for well types C and D</th></tr>
<tr><td>0</td><td colspan="2">Search and selection of suitable trees</td><td>Tools used</td></tr>
<tr><td>1</td><td colspan="2">Felling and debranching</td><td>Type 4 and 1 adzes</td></tr>
<tr><td>2</td><td colspan="2">Transport to construction site</td><td>Ropes? animals?</td></tr>
<tr><td>3</td><td colspan="2">Splitting, radial or tangential (possibly before transport)</td><td>Wooden wedges</td></tr>
<tr><td>4</td><td colspan="2">Cutting-to-length (processing end grain)</td><td>Mainly type 1 adzes</td></tr>
<tr><td>5</td><td colspan="2">Smoothing splitwood surfaces</td><td>Type 2 adzes</td></tr>
<tr><td>6</td><td colspan="2">Edging narrow sides of the boards / planks</td><td>Type 2 adzes</td></tr>
<tr><td>7</td><td>Type C: processing corner joints</td><td>Type D: processing longitudinal grooves in corner posts</td><td>Type C: bone / antler chisels, Type D : adzes or chisels</td></tr>
<tr><td>8</td><td></td><td>Type D: tapering boards towards the end grain</td><td>Type 2 or 3 adzes</td></tr>
<tr><td>9</td><td colspan="2">Erection of well lining</td><td></td></tr>
</table>

For all well types, construction pits had to be dug out before the installation of the well lining and backfilled after or during construction. The timing of these possibly independent working steps in relation to the woodworking is unclear. Therefore, only the general chronological sequence of excavation – installation – backfilling is certain. Some steps only concern the timber-framed construction types C and D. However, the first steps for all well types and generally for all wooden constructions is the search and selection of suitable trees (step 0 in ***table 1***; subsequent numbers and labelling also refer to ***table 1***). The felling and debranching (1) might have taken different efforts in time and / or team size, depending on the size of the trees. Our experiments have demonstrated that LBK adzes are adequate for felling oaks with larger stem diameters and type 1 adzes are especially effective for debranching and trimming (Elburg *et al*., 2015). The felled trees were transported (2) to the construction site and split radially or tangentially to produce boards or planks (3). Circumferential notches on two roundwood corner posts from Uničov, CZ, are interpreted as to accommodate a rope for dragging of the logs, which suggests transport of roundwood before splitting. However, the order of transport and splitting may differ in case of large stem diameters, which easily weight several 100 kg (Rybniček *et al.*, 2020). Dendroarchaeological evidence and archaeological experiments both suggest that the cutting-to-length of the planks and boards (4) happened after splitting. Occasionally, the use of fire to cut the end grain could be documented (Tegel *et al.*, 2012). In some cases of type C wells, the final cutting-to-length seems to have been implemented right before the installation of the timber (e.g. Droßdorf, n. 3619; Kretschmer *et al.*, 2016). Splitwood surfaces were smoothed (5) with adzes, at least in some cases hafted with an obtuse angle, and the narrow sides were revised more or less edged (6). In type D wells additional tapering (D8) towards the end grain was observed with thicker planks, to fit into the grooved (D7) corner post. For type C wells the corner joints had to be made (C7), from the results of the practical experiments, most probably with bone or antler chisels (Elburg *et al.*, 2015). The erection of the well lining is relatively clear in the case of type C, where interlocked planks were put horizontally on top of each other. It should be noted, however, that some examples of type C wells show construction pits, close to 15 m deep. Lobisser (1999) has already pointed out that such long well linings required certain auxiliary tools, not evidenced for the Early Neolithic, such as (wooden) spacers or bobs for vertical reference lines. For the erection of type D wells there are still a number of uncertainties remaining, such as the mutual bracing of the corner posts before the wall-filling panels are inserted. These questions will be addressed in future experiments.

Conclusion

Detailed archaological study in parallel with experimentation allowed to better understand the carpentry skills of the LBK/*Rubané* Neolithic group through their water well constructions.

These extraordinary finds provide insights into specific constructional approaches and solutions and made it possible to propose a chaine operatoire for the construction of early Neolithic wells. Some detailied questions remain unanswered for now and need to be addressed in future experiments.

Conflict of interest

No conflicts of interest to declare.

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Rénovation du calfatage d'un chaland-sablier, Mali. © P. Féron.

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