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BUILDING FORCELLO: ETRUSCAN WATTLE-AND-DAUB TECHNIQUE IN THE PO PLAIN (BAGNOLO SAN VITO, MANTUA, NORTHERN ITALY)*

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The study analyses through an interdisciplinary approach the wattle-and-daub building technique used on the Po Plain of northern Italy, focusing on the archaeological evidence from the Etruscan site of Forcello, near Bagnolo San Vito (Mantua) (540–375 BCE). Wattle and daub is widespread across different times and periods, and is particularly common in regions such as the Po Plain, where stone sources for construction are not immediately available. Thanks to a combined archaeometric, geological and anthracological study, the paper provides new insights on a fifth-century BCE building structure from Forcello. The findings reveal information on the life history of this feature, including its construction, maintenance and final destruction. The research also sheds a new light on the wattle-and-daub technique and on the interaction between people and the Po Plain Etruscan palaeoenvironment.

KEYWORDS: WATTLE AND DAUB, ANCIENT BUILDING TECHNOLOGY, PO PLAIN, ETRURIA, ARCHAEOMETRIC ANALYSES, ANTHRACOLOGY, RAW MATERIALS MANAGEMENT

INTRODUCTION

The wattle-and-daub technique and its archaeological study

Wattle and daub is a composite building material used for making walls. Wattle is the organic substructure of a wall constructed using materials such as wooden strips, sticks, reeds or bundle of straw, as well as other type of woodworks, such as planks or small beams. The precise manner by which these materials are woven or tied together is often difficult to assess in an

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archaeological context, but can be understood through ethnographic analogy (Peinetti 2016, 108–10). The wattle is daubed with a sticky material usually made of some combination of wet soil, clay, sand and possibly animal dung and straw. The main advantages of this composite material are good thermal isolation and high thermal inertia (Gheorghiou 2009, 58). Nevertheless, wattle and daub requires consistent maintenance, owing to the perishability of the material used for its construction, except if built in environments with a dry climate. For this reason, this type of architecture is poorly preserved in European archaeological contexts, unless accidental or intentional firing events burnt the daub, thus preventing its dissolution into the matrix of the archaeological deposits.

Wattle and daub is often underrepresented in the archaeological literature, not only because of problems connected to its preservation but also often because of its negligible dating and chronological value. However, studies focused on archaeological contexts discovered in both Italy and the Balkans (e.g., Ammerman *et al*. 1988; Stevanović 1997; Gheorghiou 2009), frequently with an emphasis on archaeological experimentation (Bankoff and Winter 1979; Cavulli and Gheorghiou 2008), clearly demonstrated the importance of studying this material because it gives important insights into different aspects connected to the life of past communities, such as craft traditions and the interaction between people and their environment.

In Italy, the first investigations of this material were focused mainly on the study of its morphology and typology (Tasca 1998). Nevertheless, it immediately became clear that wattle-and-daubed constructions required a more nuanced approach involving the use of analytical techniques borrowed from the natural sciences (Laviano *et al*. 1999). The first interdisciplinary study was undertaken on materials recovered from the site of Broglio di Trebisacce (Moffa 2002), and since then, the study of wattle and daub in Italy started to develop gradually into an interdisciplinary field of research, as demonstrated by the work of Peinetti *et al*. (2017, 2018). Those studies brought together for the first time the multiple strands of current research on this material from the Neolithic to the Iron Age in Italy. Despite this increasing interest, wattle and daub continues to occupy a marginal role in archaeological research, and more interdisciplinary studies are required to explore fully the potential of wattle and daub to provide information on past behaviours.

Using the case study of building materials (Croce *et al*. 2014) from the Etruscan site of Forcello near Bagnolo san Vito (near Mantua) (sixth to fourth centuries BCE), this work presents a interdisciplinary method for investigating wattle and daub that integrates archaeometric and anthracological analyses with geological and paleobotanical information. This approach allows for a degree of resolution that is not possible to achieve solely through macroscopic observation, and it demonstrates the significance of wattle and daub to the answer of numerous archaeological problems. In particular, the combination of these various techniques sheds a light on past strategies for managing raw materials as well as on the technology of daub production and use in Forcello. Additionally, archaeometric analysis provide insights into the temperatures and conditions of conflagration events such as the one that destroyed the features considered in the study.

The archaeological site of Forcello, near Bagnolo san Vito

The archaeological site of Forcello near Bagnolo san Vito (Mantua province; 16 masl, 45°06′36″N, 10°50′06″E) is located near the Lower Mincio River in proximity to its confluence with the Po River (Fig. 1). The foundation of the Etruscan settlement at Forcello dates to *c*.540–530 BCE. The site represents an important supra-regional trade centre in the Po Plain, linking the Italian peninsula, Greece and Central Europe. Forcello was subsequently abandoned

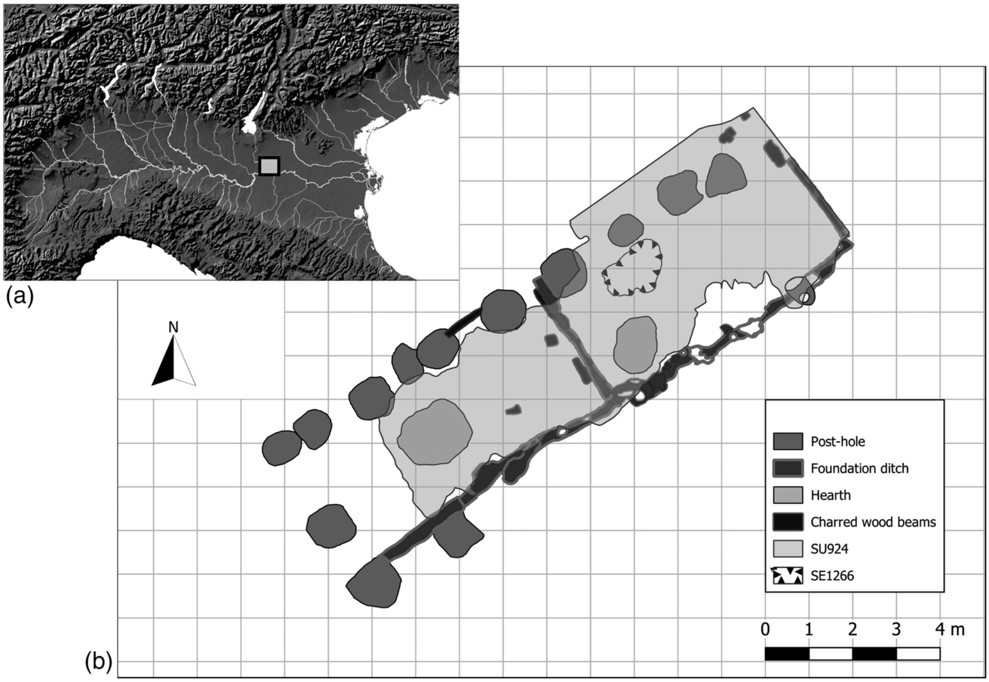

Figure 1 *(a) North central Italy, with the position of Forcello shown in the Po Plain; and (b) scaled plan of House R18–19.*

c.375 BCE, perhaps in connection with the movement of transalpine populations into northern Italy (De Marinis and Rapi 2007).

An area of about 950 m^2 (of an estimated total site extension of 12 ha) has been investigated since the 1980s by a team from the Chair of Prehistory and Protohistory of the University of Milan. The excavated area roughly corresponds to two sectors (i.e., *insulae*) defined by a regular, orthogonal street system. The ongoing excavations allowed for the subdivision of the exposed sequence into nine main stratigraphic phases, defined by different building levels, destructive fires, and episodes of reconstruction and use of areas for artisan activities (De Marinis *et al*. 2017).

During the earliest phases (G and F), the construction techniques were mainly based on an extensive use of self-supporting wooden structures with foundation trenches, broadly similar to those found at the site of Heuneburg, Germany (Quirino 2013). In the late phases (C, B and A), the buildings were constructed with a very different technique, using wattle-and-daub walls with both post-holes and foundation trenches. Nevertheless, examples of the wattle-and-daub architecture are known also from some secondary structures of the earlier phases (Castellano *et al*. 2017).

Phase C, dated to the fifth century BCE, was ended by a violent conflagration, which sintered part of the daub and destroyed the structures and contents of the building, including wooden features. The destruction level was soon sealed by different reuse levels, on top of which new buildings were constructed. Thus, the materials originated from the destruction were mainly left *in situ*. The study focuses on the materials from one layer of the destruction level (SU 924), from the structure designated as House R18–19 (Fig. 1). This layer, excavated between 2001 and 2011, has an extension of about 34.8 m^2, characterized by a copious presence of daub fragments, mixed with ceramics, charcoal and animal bones. The main wattle-and-daubed structure was rectangular, measuring 4 × 14 m, delimited by post-holes and trenches. Two rooms, divided by a small trench, could be recognized. Each housed a hearth placed directly on the ground floor. The structure can be interpreted as a portion of a sort of cluster building, probably used for both residential and production purposes (Quirino 2013; Rapi *et al*. 2016). A possible pyrotechnological installation (SE 1266) was housed in the structure.

Geology and the paleoenvironment

The site of Forcello lies on the alluvial Po Plain, which represents the foredeep of the Apennines (Scrocca *et al*. 2007). This area was characterized by deep marine sedimentation from the Pliocene to Early Pleistocene, followed by the progradation from west to east of fluvial sediments largely derived from the Alps (Garzanti *et al*. 2011). Basin filling resulted from the interaction among tectonic, climatic, eustatic and sedimentary processes. The onset of major Alpine glaciations (*c*.870 ka) (Muttoni *et al*. 2003) promoted accelerated erosion and sediment supply, leading to rapid progradation of South Alpine alluvial fans, southward displacement of the northern rivers and the eastward advancement of deltaic systems. The drainage pattern became more stable and gradually evolved toward its present configuration during the last 500 ka. Fluvial deposits rapidly occupied most of the Po Basin, and the coastline approached the present Adriatic shore.

Detailed studies of fluvial sedimentology on water-well cores that were drilled through Pleistocene sediments of the easternmost part of Lombardia (Mantova, Viadana and San Benedetto Po) document the interfingering between floodplain deposits of the paleo-Po, paleo-Oglio and paleo-Mincio rivers (Vittori and Ventura 1995; Amorosi *et al*. 2008). Present-day sediments of the Mincio are characterized by carbonate rock fragments, quartz, feldspars, volcanic and metamorphic grains, indicating a provenance from the metamorphic rocks, volcanics and sedimentary succession of the Southern Alps (Garzanti *et al*. 2006).

Studies focusing on the palaeoenvironment and vegetation of the area of Forcello have been previously published by Ravazzi (*et al*. 2013) and Castellano (*et al*. 2017). Geomorphological and stratigraphic evidence indicate that the Etruscan settlement was founded on a low hill near the shore of a former large lake (Lake Bagnolo), present in this section of the Mincio embanked valley until its reclamation in the 17th century CE (Ravazzi *et al*. 2013). The presence of continuous limic deposits in proximity to the site allowed for the recovery of a palynological sequence covering the Late Holocene (Ravazzi *et al*. 2013). The vegetation inferred by pollen data is further integrated and corroborated by the anthracological study of the archaeological deposits from the site itself (Castelletti and Rottoli 1987; Castellano *et al*. 2011, 2017; Castellano 2012). Charcoals and pollen data indicate that, at the time of the Etruscan settlement (*c*.540–380 BCE), the forest surrounding the site was dominated by deciduous oak and hornbeam, with ash, hazel, rose family trees, beech and fir as secondary floristic arboreal components. On the river and lake shore, riparian vegetation appears in stands of elm, alder and poplar. The arboreal pollen (AP) record seems to indicate that the area was well forested, with high AP values recorded until the Late Middle Age clearings (*c*.10th century CE) (Ravazzi *et al*. 2013).

MATERIALS AND METHODS

Materials

The daub remains found in House R18–19 cover an area of 34.8 m^2 and have a total weight of 751.18 kg. The whole amount of these materials was weighed and classified according to colour and textural variation. Three main typologies (Table 1) of daub were identified by Croce *et al*.

Table 1 *Summary of the different types of daub studied at Forcello*

	Type A	*Type B*	*Type C*	*Type D*
Weight (kg)	575.96	109.92	41.18	24.12
Colour	Light yellowish brown and pale yellow	Yellow, reddish yellow	Red, yellowish red with white and very pale brown rendering	Outside: pale yellow to very pale brown; inside: grey
Coarseness	Fine	Fine	Medium to fine	Fine
Inclusions	Mineral inclusions	Mineral inclusions/ organic tempering	Mineral inclusions	Mineral inclusions/organic tempering
Consistency	Hard	Medium to hard	Hard	Medium to soft

(2014) through macroscopic study. Type A is the most attested and was interpreted as the main construction material. Type B is similar to type A, but softer, and is marked by traces that could suggest addition of organic tempering (plants). Type C is the less attested and characterized by a striking red and a white layer of rendering. The latter (type C) appears to be concentrated in a specific location within the structure. These three types are marked by wattle impressions that indicate their use as building material. An additional type of daub (type D), very soft and porous, was recognized among the materials sampled in House R18–19. However, the absence of wattle impressions could indicate a different use for this material. Finally, a group of daub remains of about 2.53 kg could not have been placed in any of the established types due to its heterogeneity. Among the four types of daub identified, eight samples representing the variability observed macroscopically (Croce *et al*. 2014) were selected for archaeometric analysis. Methods applied included ceramic petrography, portable X-ray fluorescence analysis (p-XRF), X-ray powder diffraction (XRPD) and scanning electron microscopy (SEM).

Charcoal samples were collected between 2003 and 2010. These consisted of centimetric/subcentimetric charcoal fragments, already isolated in the field and handpicked by archaeologists during the excavation, by annotating their position in the plan and/or indicating their square of provenance using a 1 m^2 excavation grid. Among them, a total of 39 samples were selected for study: 26 from the house collapse level (wattle-and-daub debris, SU 924), 10 from charred wood structural elements (e.g., beams, joists) or furniture, two from post-hole fills and one from the fill of a possible pyrotechnological installation (SE1266) housed in the structure (Fig. 1).

In addition, in 2013, a preliminary raw material prospection was carried out in the area surrounding the Forcello site in order to explore the potential sources used in the production of daub at the time of the Etruscan settlement. The zone considered extends to the west of the site and represents a potential ancient terrace. The area occupied by the Bagnolo paleolake was not included in the survey, because the lake sediments were not accessible at the time in which the structure under consideration was built. Six points were considered, two of which were sampled for further analysis through pedological coring (locations 5 and 6 in Fig. 2).

Methods

Eight daub samples were thin-sectioned at the Servizi per la Geologia laboratory (Piombino) and analysed via ceramic petrographic analysis (Quinn 2013) with a Leica DM 2500P at the Institute of Archaeology, University College London (UCL) and at the Competence Center for

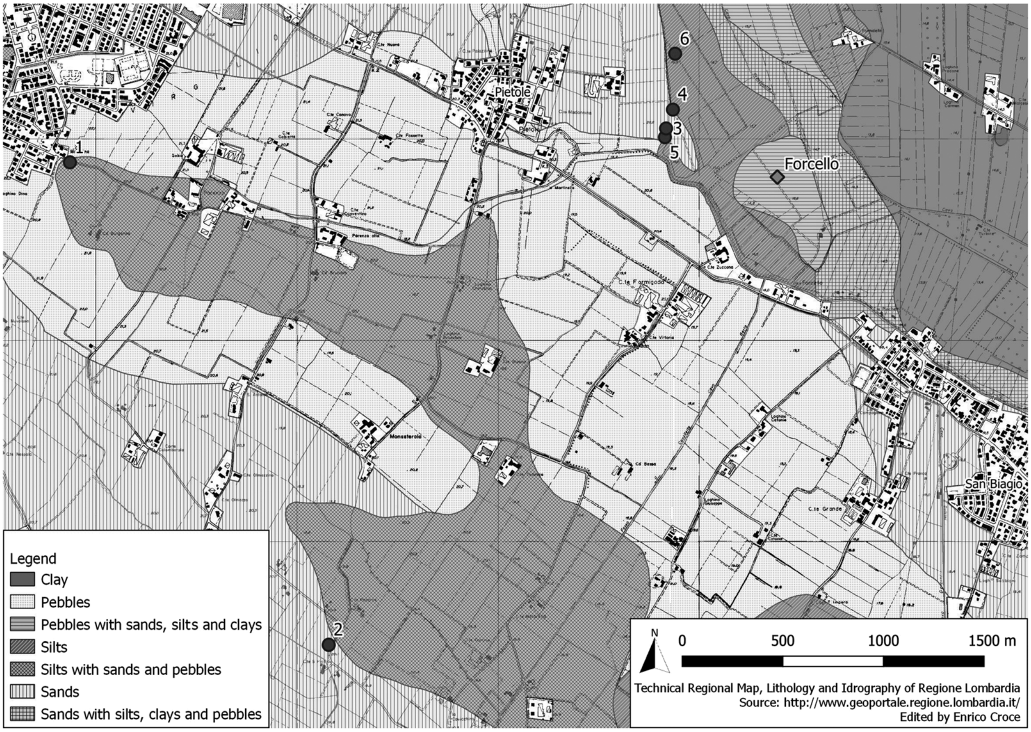

Figure 2 *Geological map of the area of Forcello. Numbered dots indicate the sampling points.*

Archaeometry Baden-Württemberg (CCA-BW, University of Tübingen). Additionally, four samples of daub were selected according to the petrographic results and analysed using XRF. This technique allows one to define the chemical profiles of the samples by measuring the concentrations of major, minor and trace elements. The specimens were analysed with a portable energy-dispersive X-ray analyser. The analyses were performed at the Goethe-Universität in Frankfurt-am-Main with a Scientific Niton XL3t with an experimental method of calibration specific for ceramic developed at this university (Helfert *et al.* 2011). The advantage of this machine is that it is non-destructive, fast and cost-efficient. However, only a small spot on the sample is analysed, which may not be representative of the composition of the whole specimen. This can be especially problematic for samples lacking a homogenous matrix. In order to minimize potential inaccuracies, at least three different points in the cross-section of each fragment were measured, and their average was calculated. The results of the p-XRF analysis (see Table S1 in the additional supporting information) for major elements were normalized to 100% in their oxide form, calculated by stoichiometry; trace elements were quantified in ppm.

A selection of daub samples was also analysed combining XRPD and SEM to gain further insight into the mineralogical composition and microstructure of the specimens. XRPD allows for the characterization of minerals that cannot be recognized in thin-section petrography owing to their small size, such as clay minerals or new phases formed during firing (Maggetti 1994). X-ray diffraction (XRD) measurements of minerals present in ceramics can also help identify the interval of temperatures at which ceramics were fired, since particular minerals are indicators of changes that occur during the firing process; examples include hematite, magnetite, cristobalite, mullite, calcite, montmorillonite, illite, vermiculite and feldspars (Maggetti 1982; Maritan 2004;

Nodari *et al*. 2007). To perform this kind of analysis, the surface layer of each sample, which normally is affected by post-depositional alteration, was removed with a tungsten carbide drill. Subsequently, small subsamples (about 2 g) were taken from each fragment and then crushed and powdered (3–5 μm grain size) in agate mortars with an automatic milling machine. The fine powder was left to dry at 110°C for 12 h. Samples were analysed with powder diffractometer Rigku MiniFlex 600 equipped with an SC-70 detector, a Cu anode (Kα1 = 1.54060) and goniometric radius of 240 mm. The analyses were accomplished with continuous scanning from an initial position of 3.0000° 2θ to a final position of 90.0000° 2θ, with 16 steps of 0.0020° 2θ s^{-1} and with working conditions of 15 mA, 40 kV. Samples were not rotated during the measurement. Mineral identification was performed by matching the diffractograms against the 2006 International Centre for Diffraction Data-Joint Committee of Power Diffraction Standards (ICDD-JCPDS) database. [Correction added on 6 April 2020, after first online: “spectra” has been replaced by “diffractograms” in this line.]

SEM helps to investigate the microstructure and degree of vitrification of ceramic materials. The degree of vitrification of the glass phase increases with the rise of firing temperatures. By examining the latter, it is possible to infer information regarding firing temperatures (Maniatis and Tite 1975, 1981). In order to carry out the analysis, a fresh fracture of the sample was covered with gold (about 2–20 nm) and analysed with a HITACHI S-3400 N using an accelerating voltage of 5 kV and an operating current of 110 μA with a variable working distance. The pictures presented in this research were taken at 2000× magnification.

Geological samples from the pedological cores collected in points 5 and 6 were impregnated with araldite, cut into standard thin sections, stained with alizarine red to distinguish dolomite and calcite, and analysed in the Provenance Laboratory at the University of Milano-Bicocca.

Preparation of charcoal samples through flotation or sieving was unnecessary because the charcoal fragments were already isolated during excavation. Following routine anthracological methods (Pearsall 1989), the three main sections (transversal, tangential, radial) of each charcoal fragment were manually exposed and observed under an optical episcopic microscope (Zeiss Axio Scope), equipped with 5×, 10×, 20× and 50× lenses and dark field/bright field illumination system. For part of the photographic documentation, we used an SEM (Cambridge Stereoscan 360). A modern charcoal reference collection (housed at the Laboratory of Palynology and Paleoecology of the CNR-IDPA, Milan) and specialized literature (e.g., Schweingruber 1990; Jacquiot *et al*. 1973) were used for identification.

RESULTS

Ceramic petrographic analysis

The results of the multidisciplinary analysis gave important insights into the building technology of the materials analysed. Ceramic petrography revealed the existence of four different petrofabrics, which correspond to the types observed macroscopically (Fig. 3 and Table S1 in the additional supporting information). Type A is marked by petrofabric 1 (Fig. 3, a, b) in which quartz and calcite are frequent. It was also possible to observe the presence of a few shells, fragments of acidic volcanic rocks (rhyolite), plagioclases, chert and clay pellets. Muscovite occur, too, but more rarely. The matrix is calcareous with moderate optical activity, light brown in Plane-polarised light (PPL) and yellow in Crossed-polarised light (XP).

Type B is characterized by petrofabric 2 (Fig. 3, c, d) with occurrence of quartz with straight extinction of volcanic origin, and polycrystalline quartz. Plagioclase inclusions and chert are common to frequent. Few inclusions of biotite, micrite, shells and intermediate volcanic rock

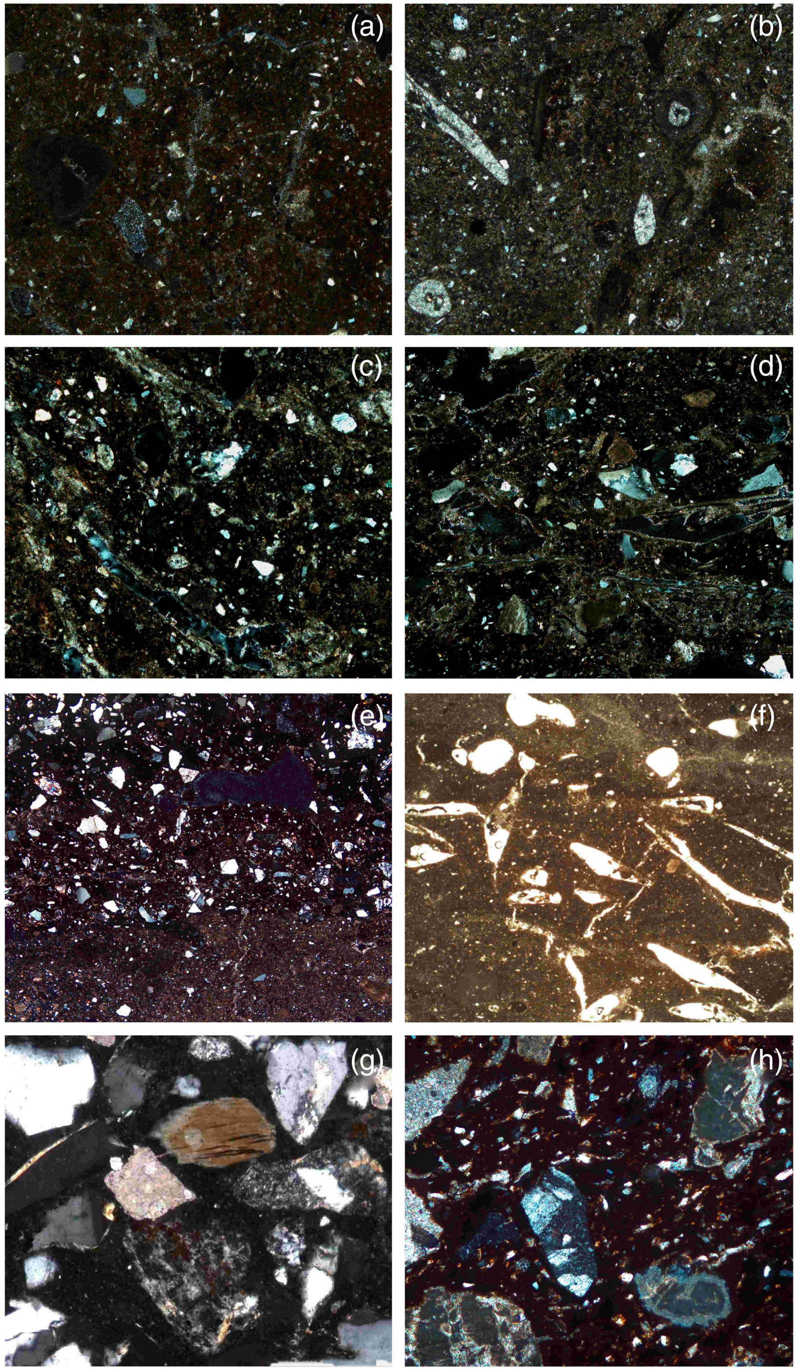

Figure 3 *Thin-section micrographs of selected samples from Forcello: (a) FR I (petrofabric 1); (b) FR II (petrofabric 1); (c) FR III (petrofabric 2); (d) FR IV (petrofabric 2); (e) FR VI (petrofabric 3); (f) FR VII (petrofabric 4); (g) geological sample collected at point 5; and (h) impasto ceramic from Forcello. Fields of view = 3 mm (a–f); and 1.5 mm (g–h). [Colour figure can be viewed at wileyonlinelibrary.com]*

fragments were observed. Fragments of metamorphic rocks, hornblende and muscovite occur rarely. The matrix is calcareous brown in PPL and reddish brown in XP and exhibits moderate optical activity and is marked by the occurrence of red clay lenses.

Type C corresponds to petrofabric 3 (Fig. 3, e) characterized by quartz with straight extinction of volcanic origin, polycrystalline quartz and plagioclase. Few to very few inclusions of biotite, chert, gneiss, acidic volcanic rock, micrite, hornblende and muscovite occur. Very rarely pyroxenes (probably augite of volcanic origin) were identified. The matrix is brown in PPL and reddish brown in XP, non-calcareous and homogeneous with moderate optical activity. The samples analysed were also characterized by a rendering layer of fine calcareous clay in which occur the same range of inclusions observed in petrofabric 1.

Finally type D is characterized by petrofabric 4 (Fig. 3, f) in which quartz and less frequently micrite, muscovite fragments of shells and clay pellets occur. The matrix is calcareous and homogeneous with moderate optical activity. All fabrics were marked by vesicular and planar voids (around 10% petrofabrics 1 and 3 and 40% petrofabrics 2 and 4) occasionally filled of charred material (petrofabrics 2 and 4). Voids in petrofabric 2 (Fig. 3, c, d) also show evidence of secondary calcite filling.

Sediment provenance analysis

During the survey we detected some outcrops (points 1–4 in Fig. 2) rich in calcium carbonate, locally known as '*castracan*'. Additionally, different sandy-clay layers were recognized in the small cores collected in points 5 and 6. (Fig. 2). Specifically, core 5 is characterized by a sandy to fine pebble layer marked by felsic volcanic and metamorphic rock fragments (gneiss and schist), with minor quantities of heavy minerals (garnet, staurolite, sillimanite and kyanite) and carbonate grains (Fig. 3, g). The lithostratigraphic sequence of core 6 includes a clay layer followed by a calcrete level and a sandy layer covering a silty-clay level. The calcrete layer is constituted by clay with a small amount of fine sand characterized by carbonate rock fragments, felsic volcanic grains and metamorphic rock fragments (metapelitic schists). Chert, muscovite, biotite and amphiboles were also recognized. These petrographic compositions indicate the sediments' provenance from the Palaeozoic and Mesozoic units of the Southern Alps (Garzanti *et al*. 2006).

Chemical analysis

Chemical analysis (see Table S2 in the additional supporting information) suggests that at least two different types of clays were used in the manufacturing of the building materials of Forcello: a calcareous clay characterized by a relatively high concentration of CaO (FR I of petrofabric 1, 39.23%; FR VI of petrofabric 3—rendering 32.70%; and FR VIII of petrofabric 4, 39.11%) and a non-calcareous clay with a relatively low content of CaO (FR VI of petrofabric 3, 2.88%). Interestingly, sample FR IV (petrofabric 2) marked by red clay lenses within a calcareous matrix still shows relatively high concentration of CaO (16.93%), but lower than in samples FR I, FR VIII and the rendering layer of FR VI. These two clays also demonstrate variations in the concentration of the trace elements, particularly that of strontium and yttrium.

X-ray diffraction and scanning electron microscopy

XRPD analysis confirmed the presence of quartz (d = 3.3 Å), feldspars (d = 3.2 Å) and calcite (d = 3.04 Å) that were also detected through thin-section petrography. In addition, XRPD allowed for the detection of chlorite or montmorillonite and illitic clay, which can be distinguished by a main diffraction peak at 14 and 10 Å d spacing, respectively, and by further peaks with variable intensities at increasing 2θ° angles (Fig. 4 above). The microstructural analysis of the fresh facture of the samples carried out with the SEM (Fig. 4 below) shows a very low degree of vitrification that typically develops at firing temperatures in the range of 800–850°C in an oxidizing atmosphere in both calcareous and non-calcareous clays (Maniatis and Tite 1981).

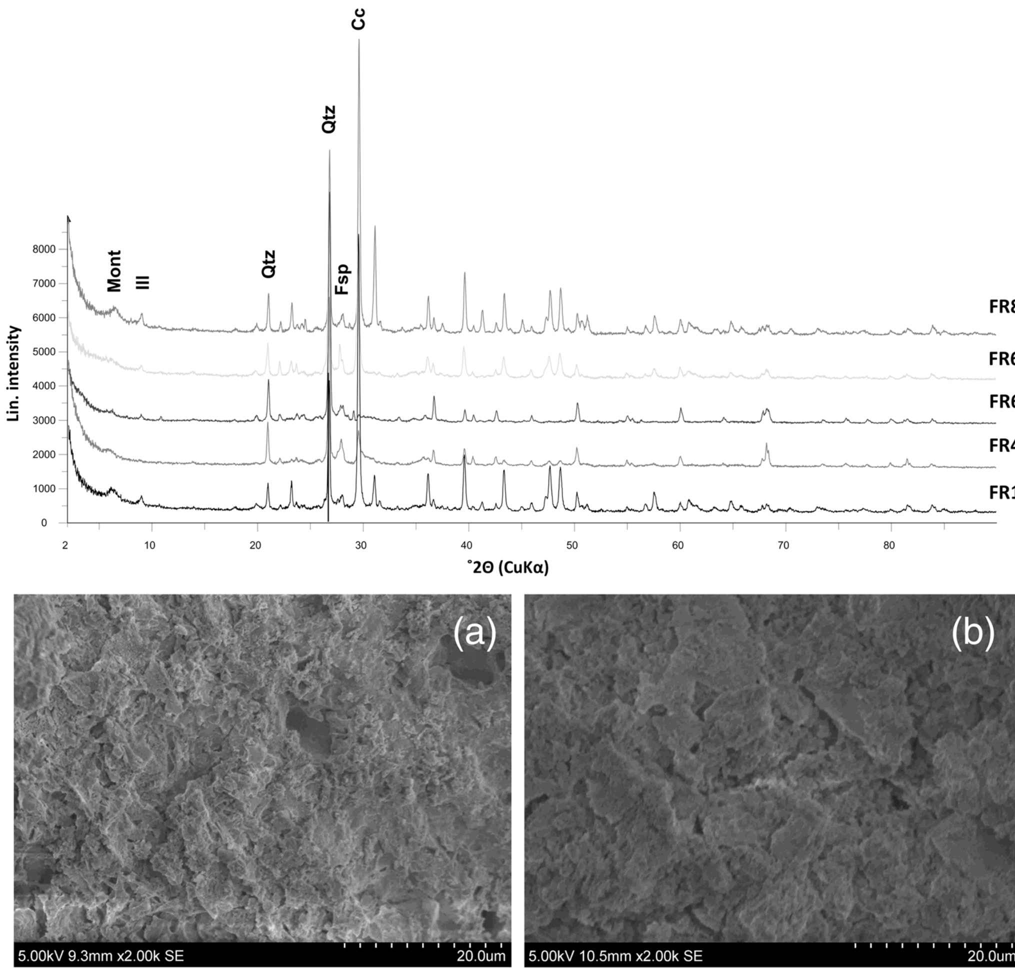

Figure 4 *(above) X-ray diffractograms (XRD) of a selection of samples from Forcello. Mineral abbreviations: Cc, calcite; Ill, illite; Fsp, feldspar; Mont, montmorillonite; Qtz, quartz. (below) Vitrification microstructure of selected daub fragments (a = FRVIII and b = FRII) from Forcello, as seen in the scanning electron microscope under secondary electron imaging.*

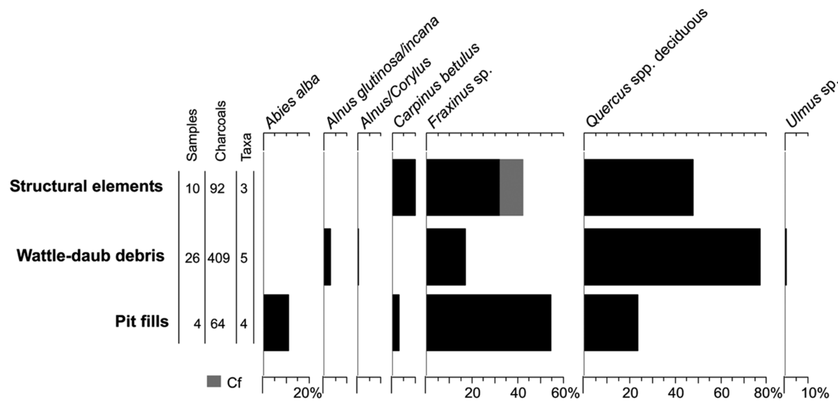

Figure 5 *Anthracological results from House R18–19. For wattle-and -daub debris and pit fills, values are calculated based on the charcoal fragment counts. For wood structural elements, values are calculated based on the ubiquity. For details, see Table S3 in the additional supporting information.*

Anthracological analysis

Following the methods described above, we analysed a total of 565 charcoal fragments (Fig. 5 and Table S3 in the additional supporting information). The anthracological association is characterized by a remarkably low floristic diversity, with a minimum of six taxa detected (Fig. 5). The wattle-and-daub collapse level shows a marked dominance of deciduous oak charcoals (*Quercus* spp. deciduous, 79% on the basis of fragment counts), followed by ash (*Fraxinus* sp., 15%). Elm (*Ulmus* sp., one charcoal) and alder (*Alnus glutinosa*/*incana*, 11 charcoals) were only sporadically attested; the charcoals from the latter taxon were all sampled from the area adjacent to hearth SU1462. The structural wooden elements, either architectural features or pieces of furniture, found on the floor of the house were made of deciduous oak (*Quercus* spp., deciduous, four of 10 samples), ash (*Fraxinus* sp., five samples) and hornbeam (*Carpinus betulus*, one sample). Ash wooden elements were found concentrated in adjacent excavation squares (R18/f-h20 and R19/h21), where the presence of a vertical loom was suggested by the excavators, on the basis of traces present on the floor. The charcoal fragments from the post-hole fills overall mirror the associations previously described, with the only exception of the attestation of fir (*Abies alba*) charcoals—unattested in the other sampled contexts discussed here. The results of the anthracological analysis are summarized in Table S3 in the additional supporting information, in terms of absolute counts, abundance on the basis of fragment counts and ubiquity.

DISCUSSION

Raw materials and use of the landscape

The combination of archaeometric analyses gave insights into the procurement of raw materials at Forcello. The results suggest that the most common type of daub recovered (type A, petrofabric 1) is made from a calcareous sandy-clay (39.23% CaO). The high content of CaO featuring this material suggests a marly origin of the clay source. The coarse fraction is not well sorted, and its mineralogical composition indicates a volcanic origin that could be connected to the lithological units of the Southern Alps. Type D is characterized by a calcareous (39.11% CaO) sandy-clay similar to that which is used to produce type A, even if the latter is a bit coarser.

Samples of type C (petrofabric 3) look such as made from a sandy non-calcareous clay (2.88% CaO), whose sandy fraction is similar to that detected in the paste of type A, but coarser. It is also interesting to notice that the samples of this type seem to be marked by a rendering layer made from the same clay used for type A. Type B (petrofabric 2) is probably made from a mixture of the raw materials used to produce types A and C. This is well shown by the occurrence of lenses of reddish non-calcareous clay within a light calcareous matrix. The mineralogical assemblages found in this paste corroborate this hypothesis, because they are the same as those detected in types A and C. It has also been noted that the CaO concentration in the sample marked by this petrofabric is still relatively high (16.93%), but lower than in 1 and 4, made only from calcareous clay. Additionally, traces of combusted organic material have been observed in voids of types B and D, therefore suggesting that organic materials could have been added intentionally in the clay paste as temper. The two types are also marked by a much higher number of voids, which are left from the combusted organic material. The mineralogical association analysed in the coarse fraction compares well with the detrital signature of the present-day Mincio River, indicating sediment provenance from the Permian volcanics and Mesozoic sedimentary cover of the Southern Alps and they have a good match with the mineralogical associations found in geological samples collected and analysed. In particular, the calcrete levels locally known as *castracan* could be the potential source of calcareous clay. These levels form through the precipitation of calcium carbonate from overlying alluvial clay layers rich in calcium carbonate. The geochemical processes that favoured the dissolution and precipitation of calcium carbonate are triggered by warm temperatures typical of summers and are responsible for the formation of nodules. The latter, during interglacial periods, became so numerous that these continuous calcrete layers developed, being marked by a fine clay fraction and small quantity of sand from the South Alpine units. It was not possible to locate the source of the non-calcareous clay, but the mineralogical association found within its sandy fraction as mentioned above well correlated with the signature of the Mincio. Therefore, the results suggest that the materials used for the construction of the building were immediately available in the vicinity of the site.

It is interesting to notice that the non-calcareous reddish clay, only sporadically used as building material at Forcello, could be the potential source used for the coarse ceramic ware production at the site. This is suggested because of the similarity observed macroscopically between the paste of type C and the one of the coarse ware, but also by some preliminary results of petrographic analysis that demonstrate that a non-calcareous clay rich in volcanic inclusions and tempered with calcite was used for the production of this ware (Fig. 3, h). However, this will be investigated with further archaeometric analysis. On the other hand, this calcareous clay rich in calcite does not appear to be appropriate for pottery-making. This is not surprising considering that > 750–800°C calcite starts to lose CO_2, which is recovered during the cooling phase; this results, respectively, in a decrease and an increase of calcite volume. However, as clay underwent a shrinkage process during firing, the reformed calcite no longer has enough space inside the ceramic body, thus causing breaks in the ceramic matrix (Picon 1995).

The anthracological flora identified (Fig. 5) is potentially entirely of local provenience. Deciduous oak, hornbeam, ash, elm, alder and fir are in fact taxa abundantly documented in the coeval pollen record from the nearby limnic sequence (Ravazzi *et al*. 2013) and from charcoal fragments sampled from other levels of the sites (Castelletti and Rottoli 1987, Castellano *et al*. 2011, 2017; Castellano 2012). As discussed by Ravazzi *et al*. (2013), the AP record suggests that at the time of the Etruscan settlement, the surroundings of the site were mostly forested, with a drop in the AP taking place only at significantly later date, around the 10th century CE, that is, with the late Medieval clearings. Thus, wooden resources were most likely abundantly available in the surroundings of the site, with a vegetation potentially entirely fulfilling the local demands for firewood and construction/manufacture timber—quantitatively not to be underestimated considering the remarkable extension of the site (12 ha). In short, the area surrounding the settlement is rich in raw materials useful for construction purposes, such as timber and easily accessible clay deposits.

Construction technique and usage

All the samples analysed represent clay-based daub. The combination of the analyses carried out on the samples does not indicate that this is a lime-based plaster (Karkanas 2007). It was not possible to detect any feature that indicates a calcination process, such as fragments of unreacted lime or partially carbonized slaked lime. Therefore, the inhabitants of Forcello made use of the locally available clay resources that were minimally processed to build the R18–19 structure. In particular, it has been noted that the main construction material was type A, made from calcareous clay, which is immediately available around the site in the form of calcrete layers. Another two types of clay pastes are present in the area, but they occur less frequently and are concentrated in specific areas. A possible explanation is that types B and C were not used during the main building event, but in the following maintenance operations, where for some reasons it was easier to employ the non-calcareous reddish clay along with the white calcareous one. That the builder of the structure had a preference for white walls is well shown by the fact that the reddish type plaster (type C) is marked by a white rendering layer made from calcareous clay.

The wooden elements found on the floor level of House R18–19 are potentially attributable to either a structural component of the building or large furniture pieces. In both cases, the marked dominance of deciduous oak and ash are easily explained by the abundant availability of those taxa in the close proximity of the site, as well as by the excellent technological value of those timbers as construction materials (Panshin and de Zeeuw 1970), and their sizes were very suitable for building purposes. The use of those taxa as construction timbers has also been suggested for other building phases from the site, most notably in the earlier (510–495 BCE) phase F houses (Castellano *et al*. 2017).

The centimetric charcoal found mixed within the daub debris of the destruction level (SU924) requires a more complex interpretation. Indeed, those fragments can be potentially attributable to either over-fragmentated architectural timbers, or wooden elements composing the wattle structures or any wood object present in the building during the conflagration. Even though this hypothesis remains unverifiable by stratigraphic or planimetric evidence, the fact that at least in part those materials are to be connected to the wattle structure is a strong possibility—as suggested by the quantities of wood that should have been present as part of the wattle structure of the perimetral walls at the time of the fire. If we accept this hypothesis, the floristic similarity between wooden structural elements and wood charcoal found within the daub debris would suggest the possibility that twigs and small branches from the same trees used as the construction timber were perhaps employed as the wattle frame of the walls of the house.

The combination of the petrography, XRPD and SEM shows that the daub material analysed was thermally processed. This probably happened during a destruction event and is not connected to an intentional process at least for what concern types A–C. However, the moderate optical activity observed in thin section, the presence of primary calcite detected through XRPD analysis and the very low degree of vitrification suggest that the temperature of this fire should have been < 850°C, probably around 750°C, which is the temperature beyond which normally glass phases start to form. In any case, the actual temperatures within the fire event are to be assumed to be spatially uneven owing to the complex dynamics in place during a fire event—including the uneven distribution of oxygen and combustible material, as shown in another case study from Forcello (Pini *et al.* 2018).

The last issue posed by this study is the possible presence of a kiln within the studied structure. The type D material characterized by chaff tempering and the absence of wattle impression could be from a pyrotechnological installation. This is suggested primarily by the fact that type D characterizes several perforated flat pieces. These could be fragments of a perforated chamber floor, above which vessels are normally placed in updraft kilns (Cuomo di Caprio 2007). Additionally, this type of material is concentrated near a pit, which has been interpreted during the excavation as correlated with a pyrotechnological structure (SE1266). However, the combination of XRPD and SEM analysis as mentioned above shows that this material was not exposed to the temperature at which normally pottery is fired in this type of installations (between 800 and ≥ 950°C; Cuomo di Caprio 2007). Nevertheless, an ongoing experimental programme directed by the leading author of the present paper demonstrates that only the parts of the kiln structures closer to the combustion chamber are likely to be significantly altered by the heat generated by the firing process (Amicone *et al.* 2019).

CONCLUSIONS

The combined interdisciplinary approach applied to the studied materials allows one to shed a new light on different aspects connected to the wattle-and-daub technique employed in the studied structure.

The study of the different types of daub recognized and the anthracological investigation enable a better understanding of the use of landscape, local crafts traditions and the technological complexity of wattle and daub that is usually neglected in archaeological accounts. In particular, this work showed not only aspects connected to the manufacturing of wattle and daub but also to the maintenance of this structure that gives further insights into the local building tradition. It is interesting to notice that in the same period, but in the ‘proper Etruria’ (Tuscany and northern Latium), the most common construction technique is instead marked by the use of stone and tiled roofs (Greco and Torelli 1983; Camporeale 2011). On the other hand, the urbanistic plan (with a regular and orthogonal street system) attested in Forcello is the same used in other contemporary Greek and Etruscan settlements such as Marzabotto (Govi 2014) and Turi (Greco and Torelli 1983). This suggests that the inhabitants of this settlement could have followed a local tradition of construction influenced by environmental constraints within a general urbanistic scheme that reflects broader cultural influences (Greek and Etruscan). The presence of elements connected to different building and urbanistic techniques fits well with the trading centre nature of this settlement which was exposed to influences from different cultural traditions spanning from the north of Europe to the Mediterranean. Therefore, this study well demonstrates that wattle and daube is an essential part of the material culture whose study can help one to have a better understanding of the past.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

SI table 1: Summary of the ceramic petrographic results.

SI table 2: ED-pXRF results.

SI table 3: Summary of the anthracological results from House R18. Absolute values and percentages are calculated on the basis of the fragment counts (Af_{nr}, %f_{nr}), and ubiquity (Au, % u). To be noted, for the wood structural elements the fragment count is an arbitrary value, being the samples composed by several large charcoal fragments generated by the same wood element. Accordingly, for those samples, abundance percentages are not calculate.

