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# Understanding technological innovations through experiment. Construction and testing of Chalcolithic pottery kilns

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***Abstract.*** *Besides its contribution to understanding the formation process of large settlements and complex social organization in the late period of Cucuteni-Trypillia, the site of Stolniceni (Republic of Moldova) provided new data on the construction and spatial distribution within the site of pottery kilns. The extensive magnetic surveys revealed a large settlement, with more than 350 burnt dwellings, hundreds of pits, ditches, paths, and 19 kilns. Of the latter, four were excavated during the 2016-2018 campaigns. Three kilns were more or less similar in terms of sizes and construction, belonging to the "simple", dual chambered, updraught type. The best-preserved of them already served as model for a published experiment conducted in 2017 near the Stolniceni archaeological base. The fourth provided several surprising building features, like six additional holes arranged around the fire channels and communicating with them, and two small clay arches above the channels' ends. A plausible hypothesis of the researchers is that these elements were meant to improve the draught, by increasing and uniformizing the circulation of hot air throughout the upper chamber. Thus, in order to test how this technological innovation acts on the firing efficiency, we conducted a new experiment (August-September 2020, Băiceni-Romania). The firing process and temperatures reached in this type of kiln proved the concern of prehistoric potters for continuous improvement of their craft, raising questions about the emergence and socio-economic implications of such innovations.*

**Rezumat.** *Pe lângă contribuția sa la înțelegerea procesului de formare a marilor așezări și a organizării sociale complexe în perioada târzie a Cucuteni-Trypillia, situl Stolniceni (Republica Moldova) a oferit noi date privind construcția și distribuția spațială în cadrul șantierului cuptoarelor de ceramică. Studiile magnetometrice au scos la iveală o așezare mare, cu peste 350 de locuințe arse, sute de gropi, șanțuri, poteci și 19 cuptoare. Dintre acestea din urmă, patru au fost excavate în campaniile 2016-2018. Trei cuptoare erau mai mult sau mai puțin asemănătoare din punct de vedere al dimensiunilor și al construcției, aparținând tipului „simple", cu două camere, cu tiraj ascendent. Cele mai bine conservate dintre ele au servit deja drept model pentru un experiment publicat, realizat în 2017 în apropierea bazei arheologice Stolniceni. Al patrulea a oferit câteva caracteristici surprinzătoare care țin de construcția sa, cum ar fi șase găuri suplimentare aranjate în jurul canalelor de foc și care comunicau cu acestea și două arcade mici de lut deasupra capetelor canalelor. O ipoteză plauzibilă a cercetătorilor este că aceste elemente au fost menite să îmbunătățească tirajul, prin creșterea și uniformizarea circulației aerului cald în toată camera superioară. Astfel, pentru a testa modul în care această inovație tehnologică acționează asupra eficienței arderii, am realizat un nou experiment (august-septembrie 2020, Băiceni-România). Procesul de ardere și temperaturile atinse în*

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*acest tip de cuptor au dovedit preocuparea olarilor preistorici pentru îmbunătățirea continuă a meșteșugului lor, ridicând semne de întrebare cu privire la apariția și implicațiile socio-economice ale unor astfel de inovații.*

**Keywords:** *Experimental archaeology, Cucuteni-Trypillia culture, Chalcolithic pottery kiln, technological innovation.*

### Introduction

The experiment is the foundation of modern science. Testing hypothesis through a trial-and-error procedure until confirmation is a powerful method to create valid premises within the hypothetic-deductive inferential process that the archaeological interpretation of material culture should be[4]. To be scientifically correct and to have a scientific output, an experiment (in archaeology or elsewhere) must follow specific scientific standards[5]. In the case of archaeology, this implies, among others, a clear hypothesis to be tested (of course, based on real archaeological finds), a proper design of the experiment, use of adequate raw materials and techniques/technologies, decent skills, flawless documentation and proper dissemination. Once here, we must denounce a series of approaches - experiences, replications, re-enactments - that self-proclaim as experimental archeology, bringing no service to archaeological science. These activities, honorable and praiseworthy, in fact, are among the hobbies or museum pedagogy, having nothing in common with the rigor and specificity of archaeological experiments.

The article describes the process of constructing and firing a kiln inspired by a recent archaeological discovery, experiment that is part of a long-term project to test different hypothesis concerning prehistoric pottery firing[6].

### The archaeological evidence

Our experiment had as a starting point a kiln discovered and investigated in the late Chalcolithic (Cucuteni B1/Trypillia C1) settlement of Stolniceni (R. of Moldova). The magnetic surveys from 2015 and 2017 (Fig. 1) provided detailed data on the structure and dimensions of the settlement. Thus, the Cucuteni site covers over 30 ha, comprising approximately 370 burned structures, three ditches, hundreds of pits and 19 ceramic kilns[7]. Of the latter, four were investigated by excavations in three successive campaigns (2016-2018). All are updraft kilns, with two chambers: a fire box, buried, composed of two fire channels, separated by a middle wall of yellow soil, and the ware chamber, covered by a dome built of clay on a skeleton of twigs above the ancient walking surface, of which only fragments have been preserved. The two chambers were separated by quasi-oval clay plates, placed above the fire channels to sustain

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[4] REYNOLDS, 1994; 1999; REYNOLDS, OUTRAM, 2008.

[5] ASCHER, 1961; KELTERBORN, 2005.

[6] TENCARIU, 2015; TENCARIU *ET ALII* 2018.

[7] ȚERNA *et alii* 2019.

the pottery and to protect it from the direct action of the fire below. Corresponding to the two channels, the kilns have two openings in front of which, on a hearth, the wood fuel burned. The access to the hearth and to the fire box was made through a pit next to the kiln.

The surprise came with the unveiling of the fourth kiln, in 2018[8] (Fig. 2). The archaeologists identified six additional holes, placed around the fire channels, to which they were connected by funnel-like openings. Two of them, were located at the ends of the channels, towards the back of the kiln, and the other four, on the sides, two on the outside of each channel. Another innovation, this time not very clear, due to the bad preservation of the kiln, is represented by the technique used for building these additional elements. After the main channels and the lateral corridors were dug, the holes were formed by building small arches on a structure of twigs covered with clay. The interpretation is that the additional holes were meant to improve the draft of the kiln, by increasing and normalizing the circulation of hot air throughout the ware chamber. Likewise, the small arches of the fire channels probably had the role of reflecting the flow of hot air (which tends to move rapidly upwards) and of "turning" it (a kind of reverberation) towards the inside of the kiln.

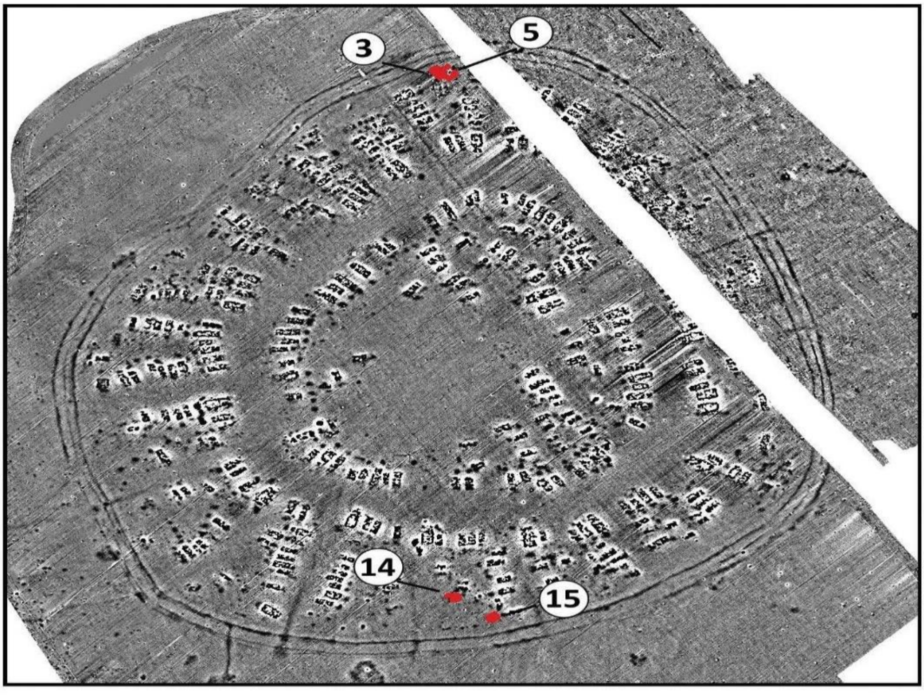


Fig.1. The magnetometric map of the Stolniceni settlement, with indication of the pottery kilns excavated so far (Țerna *et alii 2019*).

[8] ȚERNA *et alii* 2019.

**The experiment**

The unique discovery led to the idea of a new experiment to test the hypotheses related to technological innovations and how they have an effect on the efficiency of such a kiln. Thus, as previously stated, in August-September 2020, a team of archaeologists and students participated in various activities that had as final goal the firing of pottery using a kiln built according to the information obtained by the archaeological research. Activities took place on two main coordinates: 1. The making of pots and other clay objects; 2. The construction of the experimental kiln.


Fig.2. The kiln that served as model for our experiment (Țerna *et alii* 2019).

As regards the modeling and decoration of the pots, the participants in the experiment applied/used the technique of overlapping clay coils. In addition, anthropomorphic and zoomorphic pots and figurines inspired by prehistoric Chalcolithic and Bronze Age pottery were made.

Most of the efforts were focused on the construction inspired by the kiln discovered in Stolniceni (Fig. 3). First of all, a clarification is necessary: the construction of the kiln was not an experiment *per se*, but only a stage of it – our goal being to achieve the installation necessary for the experiment itself. Therefore, modern tools and containers were used to dig and construct the elevated elements of the kiln. These, however, did not alter the development and the final result of the experiment, because the following principles were strictly followed:
- The characteristics and dimensions recorded in the excavation of the archaeological discovery;
- No compromises were made regarding the raw materials used for construction: the kiln was made only of clay, water, straw and twigs);
- The quantities of raw materials used have been rigorously monitored and recorded.

Fig.3. The experimental kiln – various stages of the construction

The construction of the kiln began by arranging an area of 3 x 5 m, on which, by mechanical means (excavator), the deepening was achieved up to -1.10 m (to the yellow, sterile soil). The buried elements of the original kiln were also made on a surface deepened from the ancient walking level. The explanation, most likely, lies in the fact that the yellow soil has much more stability, eliminating the possibility of collapse of the spared elements after digging the channels, additional pits and the fire box. After leveling the area, the buried elements were drawn to the surface, and the stokers pit was dug (from which the furnace was to be refueled).

After completing the excavation of the buried elements, we continued with the application of a layer of clay 2-3 cm in thickness, on the entire surface of the fire box; previously, for better adhesion, the surfaces were coated with a semi-liquid solution of water and clay. The construction of the lower part of the kiln was completed by building the two small arches above the ends of the channels, on a twig structure. For this stage, a quantity of 85 kg of solution was needed to "coat" the surfaces and 308 kg of wet clay for the plaster. Unlike the archaeological features, the lateral holes were not furnished with arches.

The next step was to install the plates above the channels. We built the two plates directly above the channels, using a few twigs as support.

Another important moment was the placement of the pyroscopic rings inside the kiln, so we could record the temperature in as many points as possible, depending on the constructed elements involved in improving the flow of hot air: 20 of units on the surface of the kiln, 2 in the fire channels and then another 4 in the pots.

The next step of the construction was to raise the domed structure of the kiln, using, as raw materials, twigs for the skeleton and clay for the actual construction. In the case of the dome, the degree of uncertainty was higher, because, for all the kilns from Stolniceni, and not only, very few fragments of this structure were discovered (possibly because they were dismantled after each firing). At Stolniceni, several fragments of clay considered to come from the dome were discovered on the step surface near the kiln. These are fragments with a thickness of 5-6 cm, smoothed at the top, with unidirectional imprints of twigs on the back. For our construction, a circular frame of twigs was made, supported by a post, one meter height, stuck in the middle of the kiln; about 60 twigs were propped on this circular frame, fixed at the bottom with a lump of clay, in the slightly deepened edge of the kiln. Thus, a truncated cone was created, on the edge of which we started building the wall of the dome, by placing around it successive rows of clay blocks. In order to maintain the access inside the oven, we stopped the construction at the level of the initially fixed circular frame. Over the next two days, despite a prolonged autumn rain that somewhat tangled our plans, we attempted a forced drying of the oven, by light fires in the stoker's pit and around the dome.

During the morning of September 6, we took out, in the sun, the batch of vessels to be fired. It is important to mention that, for an additional relevance in terms of efficiency, we intended to load the kiln to its maximum capacity. The 25 medium and small vessels, and 13 other small objects made during the stay at the base were far from the necessary amount, so we had to improvise. The solution found was to purchase a number of 50 unfired vessels of medium size, from a local potter (Fig. 4).

Fig.4. The experimental kiln after the initial drying

The vessels were carefully arranged inside the kiln, approximately in concentric circles, so as not to waste space, but also not to obstruct the holes communicating with the fire channels. A happy coincidence made the available vessels occupy almost the entire volume of the kiln (~ 1.55 $m^3$). After filling the oven, the dome was raised by about another 30 cm. Thus, the flue of the kiln narrowed to a diameter of 25 cm. We mention that for the complete construction of the domed structure a quantity of ~ 1220 kg of wet clay mixed with straw was required, raising the total amount of clay used for the kiln to over 1600 kg. The clay for construction came mostly from a quarry near the base.

The firing (Fig. 5) started in the afternoon, after 5 pm, the kiln being gradually heated, by igniting a fire of light fuel (straw and dry twigs), about one meter in front of the fire box. Gradually, the burning fuel was pushed towards the kiln, so that, around 6 pm, the combustion was already taking place in front of the fire box. The draft was already very strong, the flames being drawn inside the kiln, through the channels. However, the humidity of the beech wood, corroborated to the length of the fire box created the impression that the firing was not strong enough (respectively, the flames were not long enough) to raise the temperature in the entire kiln to the desired level. To make up for these shortcomings, we decided to push the fire inside the fire box (7 pm). This solution seemed to work initially, because the temperature rose visibly in the ware chamber, and even a few incandescent vessels could be seen towards the base. In the long run, however, the embers and incompletely burned beech wood occupied much of the volume of the fire box, making it difficult, and later impossible to continue the supply of wood fuel, which eventually led to a drop in temperature. Thus, around 10 pm, all the wood and embers were removed from the fire box, and the fire was restarted right in front of it. This time, however, its intensity was stronger, by increasing the amount of wood burned at once. The temperature inside the oven increased rapidly. The firing continued at maximum intensity for more than two hours, and around 1.30 am, the next day, we stopped the fuel supply, pushing the embers into the channels until they refused. We also covered the flue to prevent sudden cooling of the incandescent pottery. For the actual firing, 0.7 $m^3$ of beech wood was consumed, to which is added the wood used for the initial drying and heating of the oven, so a total that exceeded 1 $m^3$.

Fig.5. The firing process.

Later, after 9 am, we found that the embers in the fire box and in front of the kiln were still active, making it impossible to extract the vessels. After removing the upper part of the dome, we extract all the vessels in the afternoon, after 4 pm (Fig. 7). Almost all the vessels looked well fired, in an oxidizing atmosphere, except for one, located in the lower back of the kiln, which was partially black (probably, it blocked the additional hole next to it, thus lacking oxygen). At the end of the firing, three vessels were cracked: one, located in the front of the oven, "benefited" from the thermal shock of the first part of combustion, while two others were damaged during extraction from the kiln. Summing up, that means a percentage of under 5% of scrap due to firing. The temperature rings were also extracted, unfortunately only 11 being sufficiently intact to be measured, the rest being crushed to the touch. Only three of them, from the front bottom of the kiln, indicated temperatures exceeding 850°C, being closer to the place of fuel combustion.

Fig.7. The burned vessels after dismantling the top of the kiln

Due to incomplete information obtained from the temperature rings, we wanted to perform physicochemical investigations, such as SEM-EDX and μFTIR analyses, for 13 samples from several areas of the kiln (Fig. 8), in order to identify the firing temperatures reached throughout the entire kiln.

SEM micrographs were used to estimate the degree of vitrification of the clay[9], and in the studied samples were not visible such traces, indicating firing temperatures below 700-750°C[10]. EDX data shows the presence of carbon in all samples, coming from carbonates and calcite, suggesting temperatures with the same values indicated by the scanning microscopy.

[9] KARAPUKAITYTĖ et al., 2006, 386; AMICONE et al., 2020, 16.

[10] PALANIVEL, MEYVEL, 2011, 340.

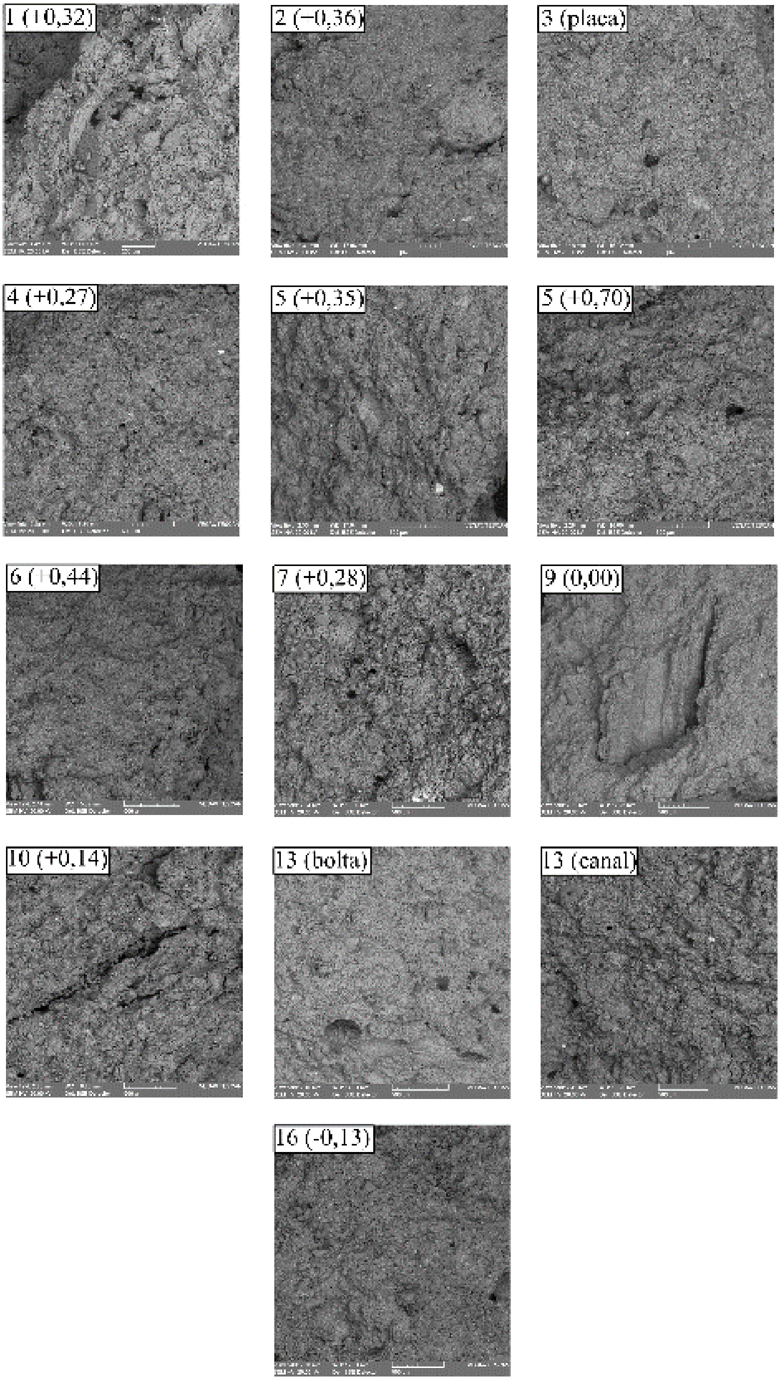


Fig.8. SEM Micrographs of the analysed clay samples.

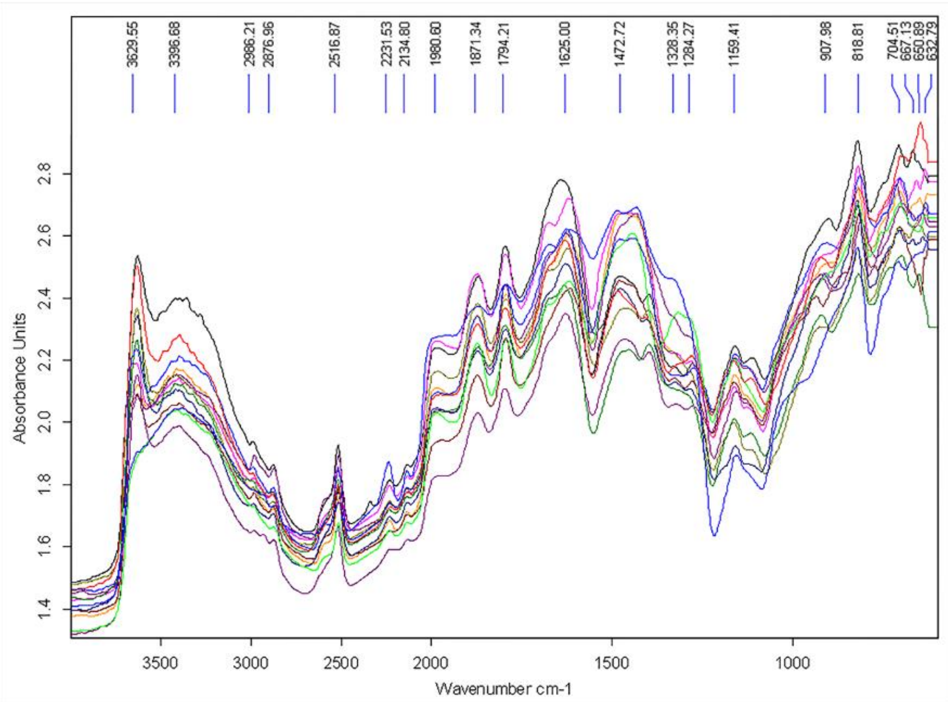


Fig.9. FTIR spectra of the the analysed clay samples

The FTIR results (Fig. 9) obtained showed, in addition to the presence of minerals specific to the used clay, a series of defining data in establishing temperature ranges. Thus, for six samples from the front area of the dome, it was established that the maximum temperature reached did not exceed 520°C[11], as determined by the presence of peaks at ~915-935 $cm^{-1}$ specific for kaolinite. The samples from the bottom area of the kiln and also from some areas of the dome reached higher values, but the presence of calcite and carbonates[12] (~2986 $cm^{-1}$, 2876 $cm^{-1}$, 2516 $cm^{-1}$, 1300-1500 $cm^{-1}$, ~704 $cm^{-1}$) indicates that the firing temperatures in the entire kiln did not exceed 700-750°C[13].

**Conclusions**

In the case of the field experiment (either the construction of an object, the use of a technology or the simulation of a behaviour in conditions) the control over the variables is

[11] VELRAJ et al., 2009, 730-731; RAVISANKAR et al., 2010, 187.

[12] NODARI et al., 2007, 4669; BERZINA-CIMDINA, BORODAJENKO, 2012, 127.

[13] RAVISANKAR *et al*., 2010, 189.

lower, but the conclusions can have a character less abstract, being convertible into valid premises within the inferential process about the past.

Regarding the experimental kiln from Băiceni, some preliminary conclusions can be drawn. All its constructive details, including the innovations (additional holes and vaults above the canals) are arguments of an advanced technology, most likely locally developed achieved after hundreds of years of experience in the pottery craft. The initial hypothesis regarding the innovations was confirmed, meaning that the elements of amplification and uniformity of the hot air worked. Although the kiln was almost completely filled with ceramic objects, until the upper opening, the whole batch heated quickly and evenly, reaching incandescence (translated by a temperature of around 600˚C), in less than an hour and a half of strong fire.

The SEM-EDX and μFT-IR analyzes performed on 13 samples, taken from the kiln's vault and from the two plates, established two intervals for the firing temperatures obtained during the experiment. The first range reaches up to 520 ° C for some areas of the dome, the other being between 520 ° C and 700-750 ° C for the bottom of the kiln. Therefore, although the firing of the vessels succeeded and the hypothesis of the functionality of the innovations was confirmed, the experiment still failed to reach the known performances of Cucuteni ceramics (over 900 ˚C). An obvious, concrete cause of this result would be the excessive humidity of the wood fuel, which burned slowly, without great temperature release. Therefore, the wood fuel must be perfectly dry and probably mixed, hardwood and softwood.

On a more general level, if we think about the reasons that led to this technological efficiency of ceramic kilns, the simplest explanation would be the larger than average dimensions, which means a larger volume of the vessel chamber and implicitly a much larger number of ceramic vessels to be heated, hence the need for a wider and faster circulation of flue gases. Following this thread, and if we go back to the archaeological context of the discovery (Stolniceni is a mega-settlement, with hundreds of dwellings, so thousands of inhabitants), then we can imagine, with little chance of error, that the demand for pottery was permanently growing, hence the need to increase efficiency by increasing the capacity of ovens. In the same context, we can think of a possible difficulty in providing the necessary amount of fuel for combustion, which could occur at some point. Obviously, wood was the essential raw material both for the construction of houses and other elements of interior architecture, and for the many domestic and craft activities, as fuel. Its intensive exploitation could have led to a relatively rapid disappearance from the catchment area of the settlement, hence the need to save it. The experiment showed that these kiln innovations could mean savings in fuel consumption - better air flow equals less wood to be burned.

Also, in the archaeological context from which we started, the magnetic map suggests an organization of "neighbourhoods" in the settlement, almost each served by pottery kilns.

Thus, we cannot rule out the possibility of a "competition" between specialized potters from the settlement (or even from different settlements), competition which is a factor of dynamism and technological efficiency.

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**Foreword**
Last, we would like to pay our gratitude and our respects to our dear friend and colleague, Stanislav Țerna, who tragically and prematurely passed away in December 2020. We also wish to dedicate all of our present and future experimental work to its memory. Rest in peace, Stas!

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