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INDICE

ABSOLUTE RADIOCARBON CHRONOLOGY OF THE ARCHAEOLOGICAL SITE OF LIO PICCOLO (CAVALLINO-TREPORTI): A MULTIDISCIPLINARY APPROACH TO A SUBMERGED ROMAN CONTEXT

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ABSTRACT

Il sito archeologico di Lio Piccolo si trova nella parte nord-orientale della laguna di Venezia, a profondità comprese tra 1,5 e 3,5 metri lungo il Canale Rigà. Scoperto inizialmente da Ernesto Canal nel 1988, è stato oggetto di indagini approfondite, compresa una pubblicazione di Valentina Goti Vola (2019), che ha proposto una datazione iniziale basata sull'esame stilistico dei numerosi frammenti di affresco trovati sul fondo del canale.

Durante le campagne di scavo condotte da Carlo Beltrame nell'estate del 2021 e 2022, è stata portata alla luce una palificata fondazionale collegata a una vasca in mattoni, rivestita da assi e pali in legno. È stato inoltre scoperto un plinto, la cui funzione rimane enigmatica. Per stabilire una cronologia precisa, è stato avviato un programma di datazione basato sul radiocarbonio sotto la guida di Elisabetta Boaretto presso il Weizmann Institute of Science. Questo programma ha coinvolto una caratterizzazione completa dell'ambiente contestuale e dei materiali, utilizzando tecniche avanzate come la spettroscopia infrarossa a trasformata di Fourier, la determinazione microscopica del legno, la dendrocronologia e la datazione al ^{14}C, consentendo un'identificazione accurata dell'età dei campioni di legno con un margine di errore di ±20 anni.

In linea con gli obiettivi della nostra ricerca, sono stati prelevati campioni da vari materiali di costruzione presenti nel sito, insieme alle sezioni di due pali: una recuperata dalla palafitta di fondazione e l'altra dal plinto. Confrontando le date al ^{14}C ottenute da diversi anelli di crescita all'interno di un determinato tronco d'albero, tramite l'elaborazione al wiggle-matching, è stato possibile individuare la data più vicina a quando l'albero è stato utilizzato. Questo studio esaustivo mira a stabilire l'anno preciso di costruzione della struttura e a chiarire la durata del periodo di utilizzo della vasca.

ABSTRACT

The archaeological site of Lio Piccolo is situated in the north-eastern region of the Venice lagoon, at depths ranging from 1.5 to 3.5 meters along Canale Rigà. Initially discovered by Ernesto Canal in 1988, it has, since then, been the subject of investigation, including a publication by Valentina Goti Vola (2019), who proposed an initial dating based on the stylistic examination of the numerous fresco fragments found on the channel bed surface.

During the excavation campaigns led by Carlo Beltrame in the summers of 2021 and 2022, a platform of foundation piles tied to a brick-lined basin, covered with wooden planks and posts, was uncovered. A plinth was also discovered, the function of which remains enigmatic. To establish a precise chronology, a particular radiocarbon-based dating program was undertaken under the guidance of Elisabetta Boaretto at the Weizmann Institute of Science. This program involved a comprehensive characterization of the contextual setting and materials, employing techniques such as Fourier Transform Infrared Spectroscopy, wood analysis, dendrochronology, and ^{14}C dating, enabling accurate determination of wood sample ages with a margin of error of ±20 years.

In line with our research objectives, samples were obtained from various construction materials throughout the site, along with two sections of posts: one retrieved from the wooden piling and another from the plinth. By comparing the ^{14}C dates obtained from different growth rings within a given tree trunk, it was possible to ascertain the date closest to when the tree was employed in construction. This comprehensive study aims to establish the precise year of the structure's construction and elucidate the duration of the basin's utilization period.

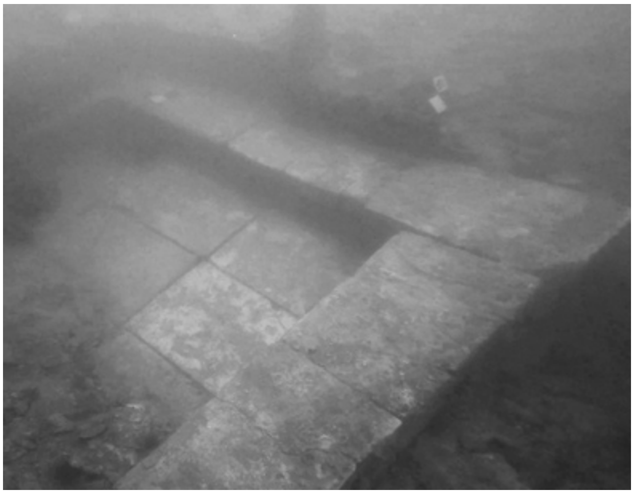

Fig. 1 - Detail of the basin viewed from the northeast.

Introduction

The submerged archaeological site of Lio Piccolo is located in the northern lagoon of Venice, along the Rigà canal, a few meters from the northwest embankment near *Agriturismo Le Saline*. After being found in 1988 by Ernesto Canal (Canal 2013, pp. 434-435) through the identification of pottery, marble fragments, mosaic tiles, and notably hundreds of fresco fragments, the site has been associated with the Roman period and interpreted as a *villa* (Goti Vola 2019). However, only recently the site has been the subject of an underwater excavation aimed at interpretation and dating. The investigations, carried out by the Ca' Foscari University of Venice under the direction of Carlo Beltrame, revealed a rectangular basin constructed with the use of bricks and wood, connected to a wooden foundation piling supporting a testimony of a foundation, made of bricks, of the presumed *villa* (Beltrame, Mozzi in press). As the initial excavation surveys did not uncover any object in the underlying layers that could provide chronological information, apart from the bricks used in the structures, the radiocarbon dating of the wooden elements has become crucial for thorough comprehension.

Site Description

The excavation activities comprised two campaigns conducted in the summers of 2021 and 2022 (Beltrame, Mozzi in this volume). These investigations revealed a sizable rectangular brick basin (USM 4) measuring 1.25 m in width (Fig. 1), with its bottom situated at a depth of -3.15 m below sea level, also constructed using bricks. The structure is covered with wooden planks (samples LPC LAG 21_S04, LPC LAG 22_S14) along the northern and western sides, inserted into the clay substrate and externally supported by wooden poles (Fig. 2). At a distance of 3.20 m from the corner along the northern wall, a wooden guide groove (LPC LAG 22_S13) was identified, intended to accommodate a wooden tablet, no longer preserved, to establish a subdivision within the basin. The structure's interior yielded numerous *Ostrea edulis* oyster shells, indicating that the feature functioned as a basin to maintain alive these molluscs. On the southern side, another vertically positioned wooden plank (LPC LAG 21_S05), measuring 1.93 m in length, possibly served a similar purpose as the other planks.
Additionally, the tank was composed also by a shorter section of a board, measuring only 0.74 m in length and running parallel to the plank (LPC LAG 21_S05) mentioned above. Adjacent to the southern side of the structure lies a wooden piling (LPC LAG 21_S01), firmly embedded into a substantial layer of clay (US2), extending nearly three meters southward (towards the embankment). In a designated area of the excavation site (LPC LAG 22_S12), the upper parts of the wooden posts provide support for remains of a foundation made of bricks (USM6) positioned at a depth of 1.35 m above sea level. Continuing along the outer side of the basin towards the east on the northern side, a brick plinth (USM5) is present, with its upper part positioned at a depth of -1.10 m above sea level. Similarly, wooden planks (LPC LAG 21_S09) inserted into the clay substrate and externally supported by wooden posts (LPC LAG 21_S08) were observed along the eastern side.

Research questions

The materials selected for radiocarbon analysis were chosen based on specific criteria to address the research questions and obtain an accurate structure dating. The samples were collected considering the following aspects:

1. Establishing the relationship between the masonry structure of the basin (USM4) and the adjacent piles supporting foundations made of bricks (US3 and USM6) was given priority. For this purpose, several samples were taken from the external

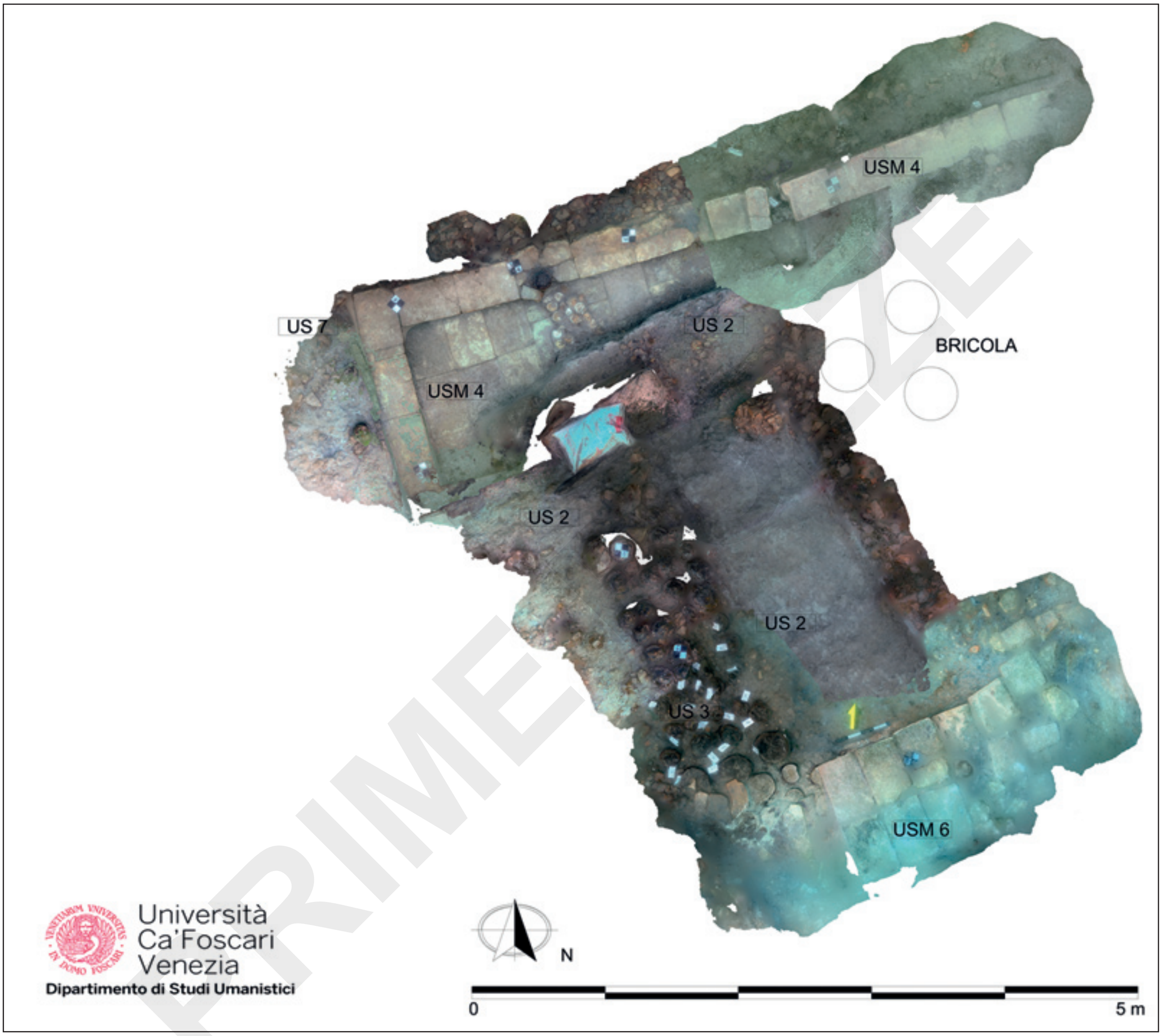

Fig. 2 - Orthophoto of the excavation area derived from a photogrammetric model.

wooden planks of the basin and the supporting posts. Furthermore, a wooden post retrieved from the pile of wood from the US3 was carefully extracted and a section was cut for ring counting and wiggle matching based on radiocarbon analysis. (Galimberti *et al*. 2004; Christen, Litton 1995). By cross-referencing the ^{14}C dating results from a single tree-ring with the number of annual tree rings separating them, a more precise dating can be obtained, minimizing potential ambiguities in the calibration curve (Bronk Ramsey *et al*. 2001). It was also considered that the external planks might serve as support or foundation and dating them could provide insights into the construction phases of the basin.

2. Verify the contemporaneity between the plinth and the basin (USM4 and USM5). One of the wooden posts associated with the plinth (Fig. 3) was sectioned to date at least two rings (using the

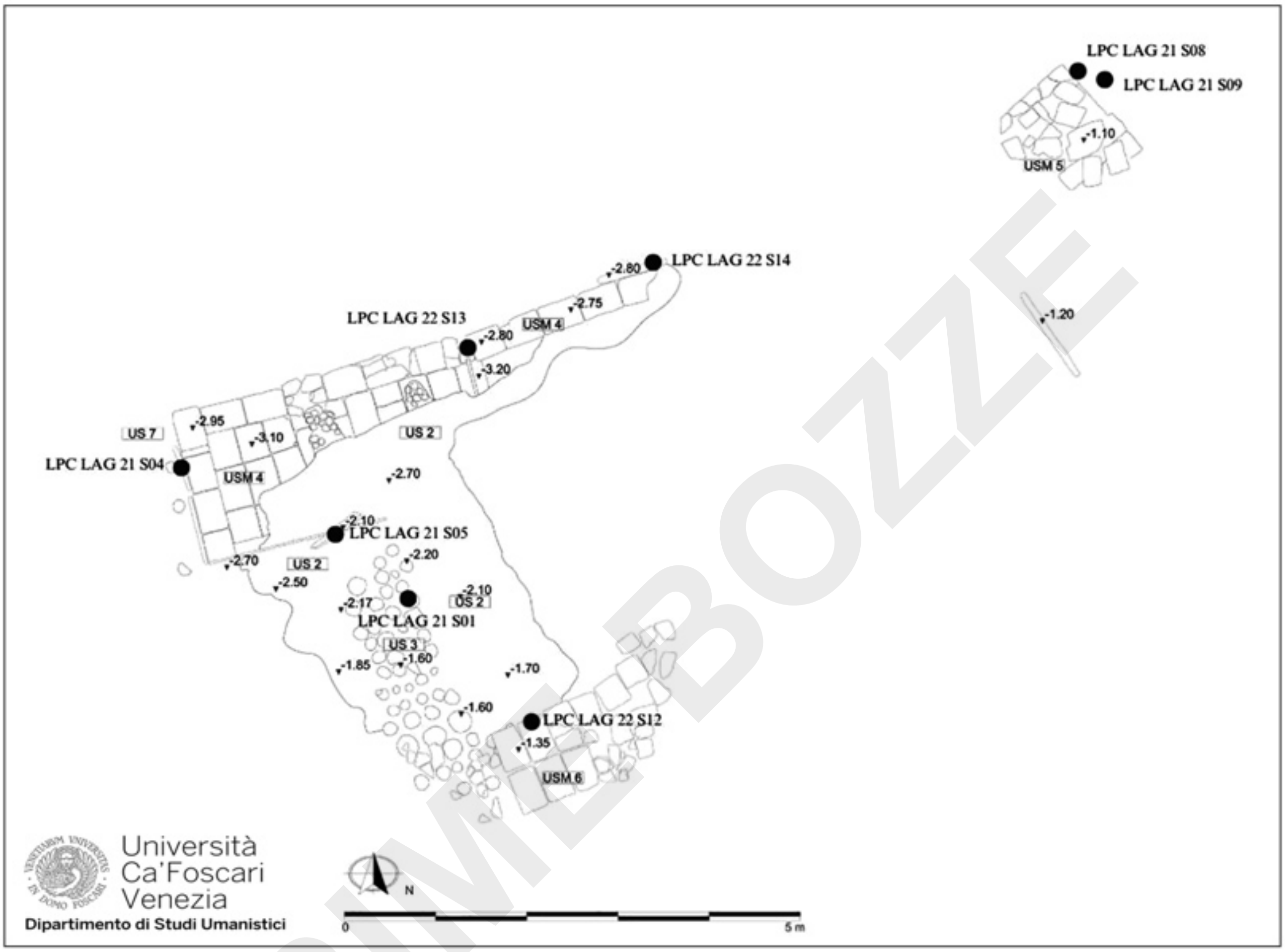

Fig. 3 - Plan view of the excavated area with marked sampling.

same approach as mentioned in point 1), along with a fragment of the external plank.

3. To determine the period of use of the structure. A wooden guide groove was identified and since it is prone to rapid degradation due to exposure to the lagoon ecosystem, it is possible that it could have been replaced over time in case of damage caused by xylotrophic organisms inhabiting the lagoon (Tagliapietra *et al*. 2016).

Dendrochronology was not employed to discern the construction phases of the Lio Piccolo site due to various considerations. The site's exceptional uniqueness is manifested both in its singular role as a *vivarium* for malacofauna, with only one comparable analogue throughout the entire Mediterranean region (Carayon *et al*. 2016), and in the distinctive feature of an external wooden plank associated with the basin, for which comparable cases are absent. These considerations initially led to the choice of an approach that minimally interfered with the site's structural integrity.
This approach is distinguishable from the procedures employed for the US3 and US5 poles, as the latter cases were characterized by a negligible risk of inflicting structural harm upon the archaeological site, and were marked by a substantial abundance of available samples.

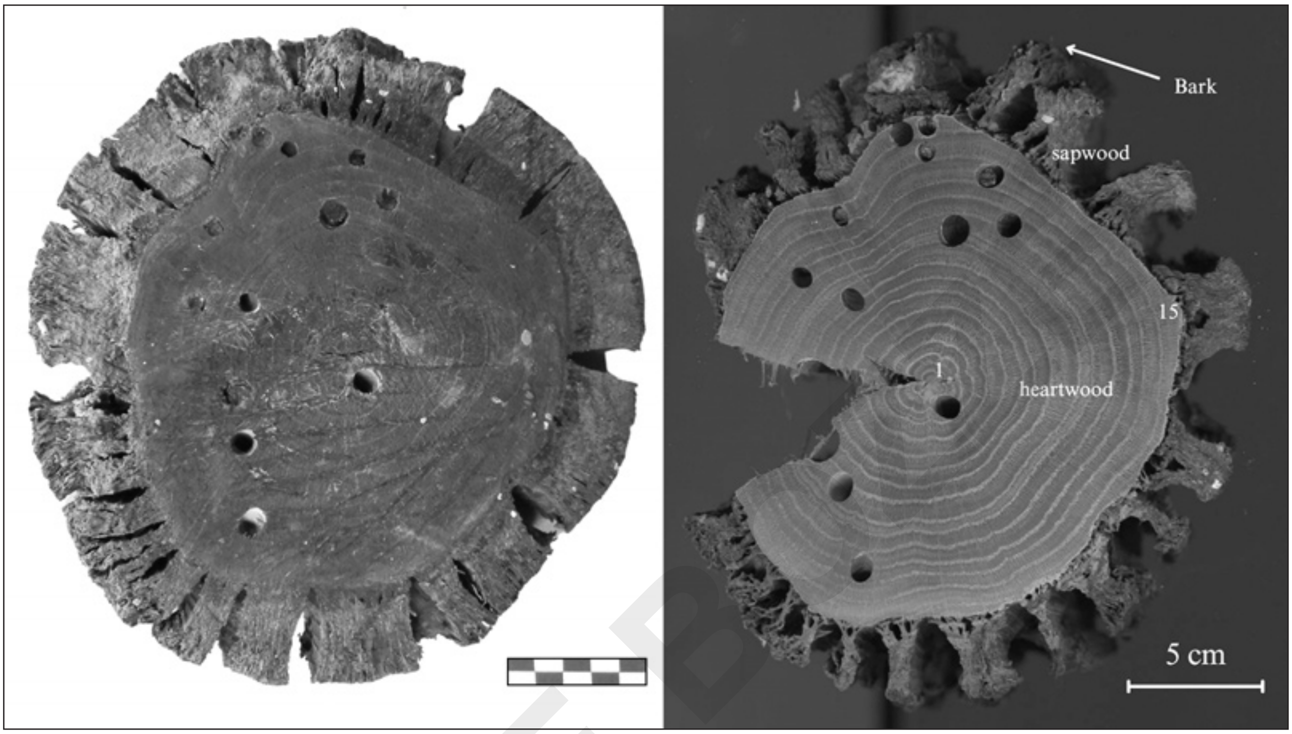

Fig. 4 - Comparison of LPC LAG 21 S01 section before and after drying.

Materials and methods

Two poles were extracted and brought to shore. There the poles were cut and two segments from each were collected for analysis. The section (LPC LAG 21_S01) was taken from the post with the largest diameter observed during the wooden piling excavation (US3). Although having the largest stem does not guarantee the presence of the longest tree-ring series, in this particular instance, under the assumption that all wood pilings were fabricated from trees that grew during the same period, selecting the largest stem increased the likelihood of obtaining the greatest number of growth rings. Furthermore, this choice was made with the deliberate aim of preserving the potential for conducting a dendrochronological analysis at a later date. The section (LPC LAG 21_S08) came from a support post of the external plinth decking (USM5). Two rings were then selected from these two sections for dating purposes. Both selected samples retained their bark. The remaining dates were performed on fragments taken from the external decking on each side of the basin: north (LPC LAG 22_S14), west (LPCLAG22_S04), and south (LPCLAG22_S05), and from the plinth (LPCLAG22_S09) (Fig. 3). Two other dates were carried out on a fragment of a post below the pavement (LPCLAG22_S12) and on a fragment of the guide groove (LPCLAG22_S13). Before analysis, all samples were dried in a controlled environment and covered with aluminium foil to prevent external contamination and ensure uniform drying (Brock *et al*. 2010, pp. 105-106). This choice was made to record the initial dry weight of the sample and calculate accurate pretreatment yields. During this period, the samples underwent significant changes in appearance, with a noticeable decrease in volume. The two post sections were particularly affected, experiencing a considerable reduction in volume and radial cracking (Fig. 4). However, it was still possible to recognize the center and edge of both sections. They were gradually sanded with sandpaper up to 1000 grit: a belt sander (Makita #9404) with five grades of grit (24, 40, 80, 150, 320) was used, followed by polishing with an orbital sander (Makita #BO5041) with four grades of grit (400, 600, 800, and 1000).

Wood species identification

Before proceeding with the dating process, all samples underwent microscopic examination to determine their species. A small fraction of each sample was carbonized in a controlled environment, inside a sealed aluminium container, at a temperature of 400°C for 1 hour. Subsequently, the carbonized samples were observed under a binocular microscope (Nikon Eclipse lv150n) at magnifications of ×20 and ×50. Microscopic observation was conducted on three different sections of the wood samples: transverse, tangential, and radial, and the results were compared with specific literature (Cambini 1967; Schweingruber 2008).

α-cellulose extraction

Wood samples were initially collected using a scalpel or, in some cases, a Dremel drill (Model 8000, 2.8 mm drill bit). The samples were then ground to obtain corresponding sawdust. For cellulose extraction, a quantity ranging from 30 to 120 mg was collected for each sample. The samples were placed in preheated borosilicate glass vials measuring 16 mm × 115 mm. All glassware, including Pasteur pipettes, beakers, and vials, was heated in an oven at 450°C for one hour to eliminate any organic contamination.

The cellulose extraction process followed the steps suggested by Ehrlich *et al*. (2017, 2021), with some modifications made to the ABA pre-treatment process. In the initial phase, the samples were treated with 5 ml of 1N hydrochloric acid (HCl) for one hour, which was conducted at room temperature. Subsequently, the samples were treated with 5 ml of 0.1N sodium hydroxide (NaOH) solution for one hour, also at room temperature. Following the alkaline treatment, a bleaching process was implemented to extract holocellulose using a method based on the Jayme-Wise procedure, as suggested by Southon and Magana (2010). The samples were treated with a solution composed of 2.5 ml of 1N HCl and 2.5 ml of 1M NaClO2 at 70°C for one hour, with heating. If necessary, this treatment was repeated until the samples achieved a white colouration. Next, α-cellulose extraction was carried out. The samples were treated with 6 ml of 5M sodium hydroxide (NaOH) for one hour. Finally, as the last treatment, the samples were treated with 5 ml of 1N HCl at 70°C for one hour.

After each phase, the samples were thoroughly rinsed with distilled water until reaching a neutral pH. Subsequently, the samples were dried in an oven at 100°C overnight to altogether remove residual moisture.

Radiocarbon dating

For dating purposes, around 3 mg of desiccated -cellulose is carefully measured and placed in a tin capsule, which is subsequently combusted in an Elemental Analyzer (EA Elementar vario ISOTOPE) linked to an Isotope Ratio Mass Spectrometer (Elementar AMS precision IRMS) and an Automated Graphitization Equipment (Ionplus AGE 3). A fraction of CO2 resulting from sample combustion in Elemental Analyser is analyzed in the IRMS and the rest is graphitized over iron powder by AGE 3 (Raj *et al*. 2023). The determination of the ^{14}C content was performed at the DANGOOR Accelerator Mass Spectrometry (AMS) Laboratory at the Weizmann Institute of Science. All calculated ^{14}C ages were corrected for isotopic fractionation based on the stable carbon ratio ($\delta^{13}C$ value) obtained through AMS. The calibrated ages, expressed in calendar years, were determined using the IntCal20 calibration curves for the Northern Hemisphere (Reimer *et al*. 2020) and OxCal v4.4 (Bronk Ramsey 2009). The dates were modelled using the Bayesian wiggle-matching method (Bronk Ramsey *et al*. 2001).

Results

A total of ten samples were selected for analysis. Upon microscopic inspection, the botanical identification of these samples was made based on specific anatomical features, such as ray width (uni- and multiseriate), perforation plates (simple), and the absence of spiral thickenings, concluding that they belonged to the species *Quercus Robur*, a deciduous oak. This species is common in the Mediterranean region (Schweingruber 1988, p. 28) and was extensively used for construction purposes in ancient times (Haneca *et al*. 2009). The growth rings were counted by observing the samples under an optical microscope: the LPC LAG 21_S01 section had 22 rings with a clear distinction between heartwood and sapwood, while the LPC LAG 21_S08 section had only eight rings. Additionally, both sections showed the presence of bark, accurately determining the last year of growth (Aitken 1990, pp. 61-75; Weiner 2010). The dating was performed on the first and fifteenth rings for LPC LAG 21_S01 and on the first and eighth rings for LPC LAG 21_S08. Dating different rings and knowing the number of intermediate ones helps reduce the margin of uncertainty, obtain a more accurate dating, and prevent ambiguity in cases where it coincides with a plateau in the calibration curve.

Furthermore, a pre-screening of all samples was conducted using FTIR to determine their degree of preservation and obtain information about their chemical composition (Ehrlich *et al*. 2017; Hook *et al*. 2015). The analysis confirmed the chemical composition of the samples (Nandiyanto *et al*. 2019), mainly consisting of lignin and cellulose, and revealed a low degree of preservation of the latter (Weiner 2010, pp. 309-311). The extraction process of α-cellulose was successfully carried out on all samples without observing any contamination, ensuring accurate dating. The results of the radiocarbon dating for the selected samples and their respective origins within the excavation site are presented in Table 1 below. The dates are expressed in calibrated calendar years with a confidence interval of (±2σ). The wiggle-matching-modulated dates for the post sections are also indicated (Bowman 1990, p. 48).

Archaeological Contest	Sample	Lab #	Ring #	C %	Libby age ± 1σ year BP	Calibrated date (± 2σ)	*Wiggle-machting* (± 2σ)
US3	LPC LAG 21_S01a	RTD 11630	15	35,4	1937 ± 21	21 (90.8%) 132 AD 140 (3.1%) 160 AD 190 (1.5%) 201 AD	15 (95.4%) 104 AD
	LPC LAG 21_S01b	RTD 11631	1	31,8	1991 ± 21	43 BC (92.9%) 80 AD 99 (2.5%) 109 AD	30 (95.4%) 120 AD
USM4	LPC LAG 21_S04	RTD 11764	-	39,3	2031 ± 21	97 (6.9%) 71 BC 58 BC (84.6%) 30 AD 40 (3.9%) 60 AD	
	LPC LAG 22_S13	RTD 11792	-	38,6	2054 ± 21	151 (4.5%) 131 AD 120 BC (90.9%) 18 AD	
	LPC LAG 22_S14	RTD 11793	-	39,8	1771 ± 23	231 (24.4%) 265 AD 271 (71.1%) 350 AD	
	LPC LAG 21_S05	RTD 11632	-	28,3	2164 ± 22	354 (43.5%) 283 BC 230 (48.3%) 146 BC 138 (3.6%) 110 BC	
USM6	LPC LAG 22_S12	RTD 11791	-	36,2	1951 ± 21	31 (1.6%) 16 BC 6 (93.8%) 128 AD	
USM5	LPC LAG 21_S08a	RTD 11633	8	42,3	1900 ± 22	76 (95.4%) 214 AD	128 (94.1%) 248 AD
	LPC LAG 21_S08b	RTD 11634	1	28,5	1834 ± 21	128 (94.1%) 248 AD 299 (1.4%) 30 AD	126 (95.4%) 214 AD
	LPC LAG 21_S09	RTD 11635	-	12,8	1876 ± 32	80 (5.0%) 100 AD 108 (90.5%) 239 AD	

Tab. 1. - Information about the archaeological context, sample labels and radiocarbon data for the Lio Piccolo samples.

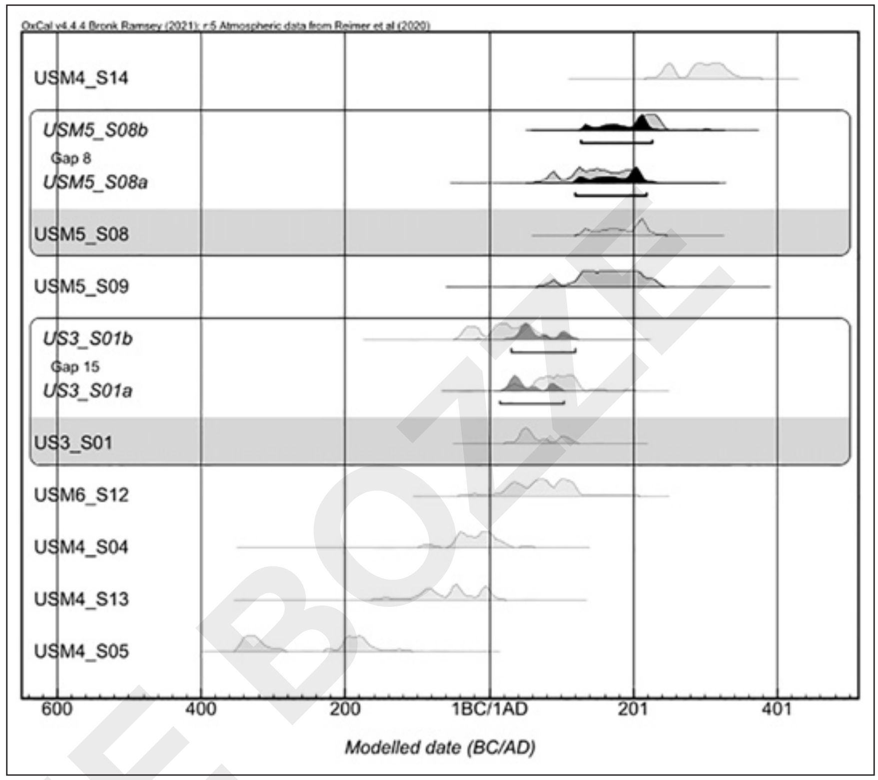

Fig. 5 - Results from radiocarbon dating.

Discussions and conclusions

The bark still attached to the foundation piles suggests that the time between felling and construction use was insufficient for it to detach naturally. The time it takes for the bark to detach from a tree completely can vary and is influenced by several factors; in the case of oak, it is approximately one year. It should be noted that foundation piles, once driven into the ground and covered by sediments, begin to consolidate and harden, becoming very resistant. This natural chemical process renders the seasoning of wood for such purposes unnecessary. The fact that the foundations are constructed with oak wood is consistent with what Vitruvius described in Book II, Chapter IX of his *De Architectura*, where he states:

> «contra vero quercus terrenis principiorum satietatibus abundans parumque habens umoris et aeris et ignis, cum in terrenis operibus obruitur, infinitam habet aeternitatem».

Therefore, these species are suitable for use as the foundation of coastal structures and for the consolidation of marshy areas, although according to Vitruvius, alder is more suitable for this purpose, especially in the construction of pilings to support masonry works (Vitr, II, cap IX 10-11).

Based on the collected data and the conducted dating project, it can be assumed that the trees used in the construction of the site were cut and immediately utilized. Therefore, the modelled wiggle matching dating of LPC LAG 21_S01a (Fig. 6) can be considered as the approximate dating of the site's construction (15-104 AD, see table 1), to which seven calendar years need to be added, corresponding to the seven missing growth rings after the one sampled to reach the year of felling (one per year) that counts 22 rings. This conclusion is supported by the consistency between the dates of the timber around the basin (USM4) and the dating of the brick foundation (USM6, in green in Fig. 5). As for the plinth (USM5), whose function is still to be defined, at the moment, we can hypothesize that it was built toward the end of the 2nd AD, one century after the construction of the basin (in red in Fig. 5). It is interesting to note that the dating of the wooden guide groove (LPC LAG 22_S13) slightly predates that of the basin against our assumption (see point 3 in the

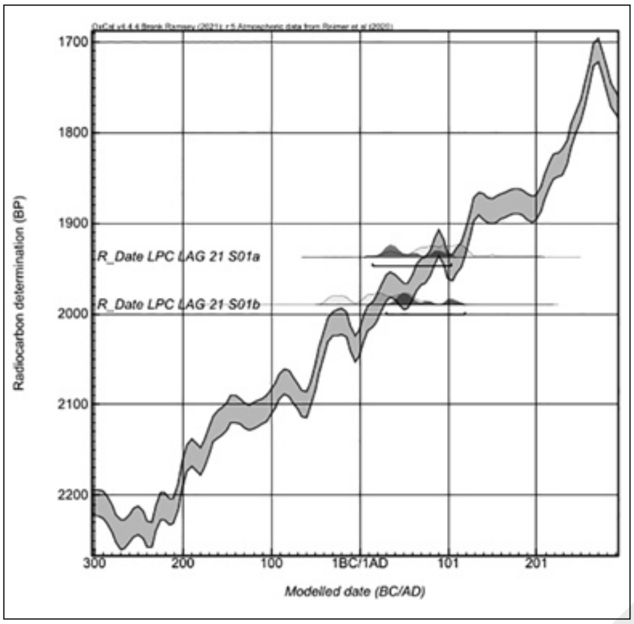

Fig. 6 - Wiggle matching of LPC LAG [illegible]ng sequence on the calibration curve.

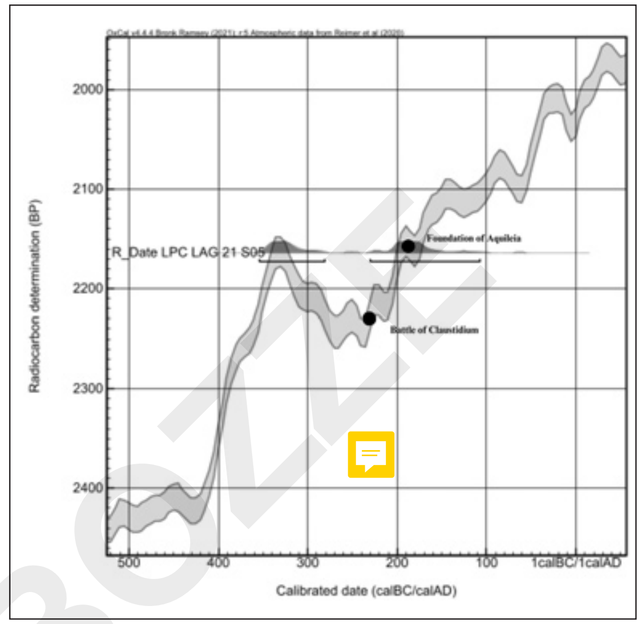

Fig. 7 - Calibrated dating in calendar years of LPC LAG 21 S05 with major historical events of Roman conquest in Veneto.

Research Questions). Our suggestion is that this could have been made from the heartwood of a much older oak compared to those used for the wooden piling (US3) and properly seasoned to increase its resistance to the lagoon water. In this case, the beam may have never been replaced during the entire use of the basin, indicating a possible short lifespan of the basin itself, although this hypothesis contradicts the fact that the plinth has a temporal gap of over a century.

Furthermore, the dating of LPC LAG 22_S14 provides significant indications regarding the prolonged use of the basin, suggesting that its use is not less than two centuries (Fig. 5). The board from which the sample comes is situated between the beam and the plinth and may have been added later to reinforce the structure.

The last controversial dating concerns the sample LPC LAG 21_S05, taken from the external planking on the south side, between the basin and the wooden piling. This dating could fall between 354 and 283 BC (43.5%) or 230 and 146 BC (48.3%). Considering the historical data, we exclude the older dating since the Roman colonization of *Veneto* begins with the Battle of *Clastidium* in 222 BC, followed by the foundation of the colony of Aquileia in 181 BC, and an increasingly widespread control of the Veneto territory with the construction of the *Via Annia* (131 BC) and the foundation of *Altinum* (Migliario 2010) (Fig. 7). However, the reason for this apparent discrepancy with the other dates remains unclear. The date suggests the possibility of a large (~150-200 years) "old wood effect" (Bowman 1990, p. 51), implying that a growth ring from the early years of a very mature plant was inadvertently sampled. The temporal gap of more than a century required to match the basin's dating could be attributed to the oak sample, as oaks are long-lived plants with a potential lifespan of up to 500 years, although they rarely exceed 200 (Schweingruber 1988, p. 28).

Finally, it can be observed that, although the interpretation based on the radiocarbon date proposed by Ernesto Canal (150 AD-10 BC, Goti Vola 2019, pp. 54-55) slightly precedes ours, placing the site between the late Republican and early Imperial periods, our chronology aligns with Goti Vola's proposed timeline, based on the stylistic analysis of fresco fragments, situating the site between the 1st and 2nd centuries AD. The slight discrepancy between the two sets of dates could stem from the sampling of one of the inner rings of the palisade posts, for which unfortunately Canal does not provide a clear sampling procedure. As we have explained, sampling different rings can yield significantly different results. Furthermore, these meticulous analyses and our research have revealed an extended usage of the site, surpassed earlier estimations and extended the timeline to at least the 3rd century AD (Fig. 5). Further scrutiny holds the potential to address unresolved queries, particularly concerning the dating LPC LAG 21_S05, which exhibits a significant difference from the others.

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PICTURE REFERENCES

Fig. 1: photo by Elisa Costa.
Figg. 2-3: graphic processing by Elisa Costa
Fig. 4: photo by Enrico Chiorrini.