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Transoceanic Contact of Suvaṇṇabhūmi: Shipbuilding Innovation and Cross-Cultural Exchange in the Proto-Historical Thai-Malay Peninsula

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In the first millennium CE, the area of the Thai-Malay Peninsula is considered a hub that accommodated maritime trade connecting East Asia, India, and the Mediterranean. Imported artefacts from archaeological sites (proto-historical port sites) and historical archives reveal overseas trade via maritime cross-cultural contacts. Besides, ancient shipwrecks offer concrete proof of the region's technological expertise. This article explores the socio-cultural and technological advancements of the proto-historical period by comparing two distinct shipwrecks discovered in Thailand. One vessel demonstrates the adaptation of imported Mediterranean-style shipbuilding techniques using native Southeast Asian materials, while the other exemplifies the Southeast Asian's local shipbuilding traditions. By evaluating these differing approaches, this research challenges strict, linear evolutionary timelines of maritime technology. Ultimately, the study posits that early maritime engineering in the Thai-Malay Peninsula was not the result of passive cultural diffusion, but rather of a sophisticated blend of localised innovation and imported knowledge adapted for specific environmental and practical needs.

Keywords: Southeast Asian shipbuilding, lashed lugs, mortise & tenon, Thai-Malay peninsula, Maritime contact

Introduction

Shipwrecks provide crucial empirical evidence of ancient transoceanic contact. Across the Thai-Malay Peninsula, shipwrecks and associated imported artefacts have been discovered. From a maritime archaeological perspective, fragments of these vessels display a remarkable variation in maritime technologies. The Thai-Malay Peninsula acted as a centre for maritime contact from around the 3rd century BCE. Evidently, both historical records and artefacts indicate that this was a period of early-stage cross-cultural exchange. Simultaneously, the shipwrecks found within this timeframe provide important insights into the construction techniques and the origin of materials obtained by ancient shipwrights. They reflect the technological capabilities of an ancient society, environmental adaptations, and cultural identity.

This article aims to provide historical and archaeological evidence of maritime cross-cultural contact, establishing a foundational understanding of Southeast Asian maritime networks during the proto-historical period. Furthermore, it investigates the socio-cultural and technological development of the Thai-Malay Peninsula through two distinct archaeological discoveries in Thailand: the Pak Khlong Kluay (PKK) shipwreck

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(200-140 cal. BCE), featuring Mediterranean-style locked mortise-and-tenon joinery, and the Khlong Thom (KT) shipwreck (85-229 cal. CE), exemplifying the indigenous Southeast Asian "lashed-lug" tradition. By analysing the morphology, assembly techniques, and local material procurement of these vessels, this study re-evaluates existing evolutionary frameworks of regional shipbuilding traditions.

Historical Documents

Historical and cartographic records confirm that cross-cultural contacts occurred between Southeast Asia, the Mediterranean, India, and East Asia. This was established by the first millennium CE. Early Roman texts, Indian records, and Chinese chronicles, for example the *Hou Hanshu* document the mutual recognition and early commerce (Chattopadhyay, 2018, p. 11; McLaughlin, 2010, pp. 18-19; Young, 2003, p. 1). By 150 CE, Ptolemy's treatises reflected sophisticated Greco-Roman spatial knowledge of these interconnected regions (Ptolemy & McCrindle, 1885, p. 189). However, direct overland trade between Rome and China was obstructed by Parthian intermediaries safeguarding their silk trade (Hill, 2009, p. 25; Hirth, 1885, pp. 70-72).

To avoid these overland bottlenecks, merchants redirected operations toward maritime networks traversing Southeast Asia. By the first century BCE, the Southeast Asian region had adopted "Indianisation" (Cœdès, 1975, p. 14), and supported expanding Chinese maritime activity (Perez-Alvaro & Forrest, 2018, p. 377). This maritime resolution unblocked direct diplomatic ties between regions and helped to establish exchange through maritime contact. A Roman delegation, dispatched in 166 CE, successfully bypassed Parthian territory by navigating through Southeast Asian coastal areas to reach China, as stated in the Liang-Shu records (Hirth, 1885, pp. 47-48).

Subsequent Chinese historiography and the detailed navigational accounts of Buddhist pilgrims like Faxian and Yijing vividly capture the scale of these maritime corridors (Hirth, 1885, p. 47; Sen, 2006, pp. 25-33). Cumulatively, these textual sources illustrate that the Thai-Malay Peninsula and the broader Southeast Asian region functioned as indispensable, highly integrated nodes in the genesis of global maritime trade.

Archaeological Evidence of Maritime Exchange in Thailand and Southeast Asia

In Southeast Asia, the earliest documented community is Funan (late 1st to 2nd century CE), centered in southern Vietnam with its principal harbour city at Oc-Eo (Cœdès, 1975, p. 14; Manguin & Stark, 2022, p. 637; Stark, 2006, p. 146), Oc-Eo featured a centralised city and an extensive canal network, it facilitated resource exchange with upland settlements (Manguin & Stark, 2022, p. 647; Saraya, 1988, p. 90). Regionally, cross-cultural interaction is further marked by the widespread distribution of Sa Huynh-Kalanay pottery dating within 2,000 BP (Favereau & Bellina, 2016).

In southern Thailand, proto-historical coastal communities evolved into major trading ports. On the eastern coast, Chumphon's Khao Sam Kaew (4th century BCE to 1st century CE) demonstrates early global connectivity through imported beads, Han ceramics, and Sanskrit inscriptions, while the Khao Ta Plai rock shelter site shows a long period of human occupation (Bellina-Pryce & Silapanth, 2006, pp. 272-273; Bowonsachoti, 2023, p. 42).

Along the western coast, Phu Khao Thong in Ranong (2nd century BCE) and the site of Bang Kluay Nok have yielded Han pottery, rouletted ware, Indian-Roman beads, precious ornaments, and a Roman intaglio, showing stylistic links to Oc-Eo, Prohear, and Java (Chaisuwan & Naiyawat, 2009, p. 107; Kangked, 2009, pp. 49-50; Ploymukda, 2020, p. 42). The Pak Klong Kluay (PKK) shipwreck further underscores these direct transoceanic ties (Kimura, 2022, p. 100; Ploymukda, 2020, p. 46). Further south, Kuan Luk Pad (KLP) in Krabi served as a major industrial hub for local bead production and a crucial Indian Ocean trade community,

corroborated by 1st- to 7th-century Brahmi and Pallava script seals (Borell et al., 2014, p. 99; Thongkam, 2009, p. 120; Veeraprajak, 1986, p. 7). The widespread distribution of Dongson bronze drums, including 21 specimens recovered in southern Thailand at sites like Khao Sam Kaew and Samui Island (Bellina-Pryce & Silapanth, 2006, p. 272), further highlights the extensive reach of regional interaction networks during this era (Miksic, 2017, p. 561).

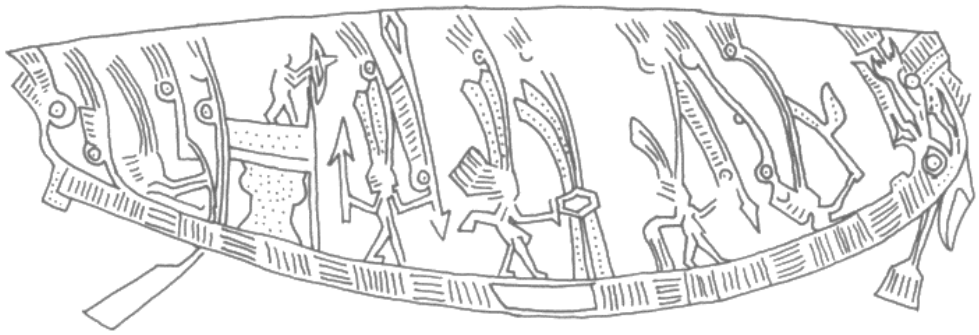

Figure 1. A relief on a Dong Son drum depicting a boat and people (Solheim, 1989, p. 27).

Shipwreck

Shipwrecks serve as more than just direct, empirical evidence of maritime interactions; their specific details reveal crucial aspects of cross-cultural connections. The study of shipbuilding technology, including the diverse techniques and materials utilised, allows archaeologists to trace the trajectories of these methods and ultimately determine the specific origins of individual vessels. Because ships employed in maritime trade relied on a network of ports, they functioned as craft for transporting cultural artifacts across oceans, facilitating exchange between multiple communities and cultures.

Accordingly, this article presents archaeological interpretations of morphology of the ships, specific construction techniques, and component materials based on shipwreck evidence discovered in Thailand dating from the 2nd century BCE to the 3rd century CE. Specifically, this study examines two distinct vessels featuring different construction methods: the Pak Khlong Kluay and Khlong Thom shipwrecks.

The details of each vessel are as follows:

Pak Khlong Kluay Shipwreck (PKK)

The shipwreck was discovered by local fishermen in late 2016, on a beach, to the north of Cape Kluay (Laem Kluay in Thai) and it is situated in a palm tree plantation. The site is located in Na-Kha Subdistrict, Suk-Samran District, Ranong Province, Thailand. The vessel was found within the territory of the Bang Kluay Nok archaeological site, an ancient port during the proto-historical period (Chaisuwan & Naiyawat, 2009, p. 107). Furthermore, it is located within the area of the Phu Khao Thong archaeological complex (PKT), an ancient port site. The PKT port and PKK shipwreck site are connected by the Kluay Canal (Khlong Kluay in Thai) (Ploymukda, 2020, p. 42). This represents a highly significant discovery of a shipwreck situated directly within an established ancient port zone. The site was initially investigated by archaeologists from the Fine Arts Department (FAD) and the Underwater Archaeology Division (UAD). The archaeological team identified hull timbers featuring edge-to-edge mortise-and-tenon joinery, collected samples for dating, and temporarily protected the exposed remains *in situ* with geotextiles and sandbags (Ploymukda & Piromrak, 2019, p. 6). However, because the temporary *in situ* preservation using sandbags proved ineffective, a full excavation was conducted in 2019 to completely recover

all the hull planks from the PKK shipwreck site (Piromrak, 2023, p. 3).

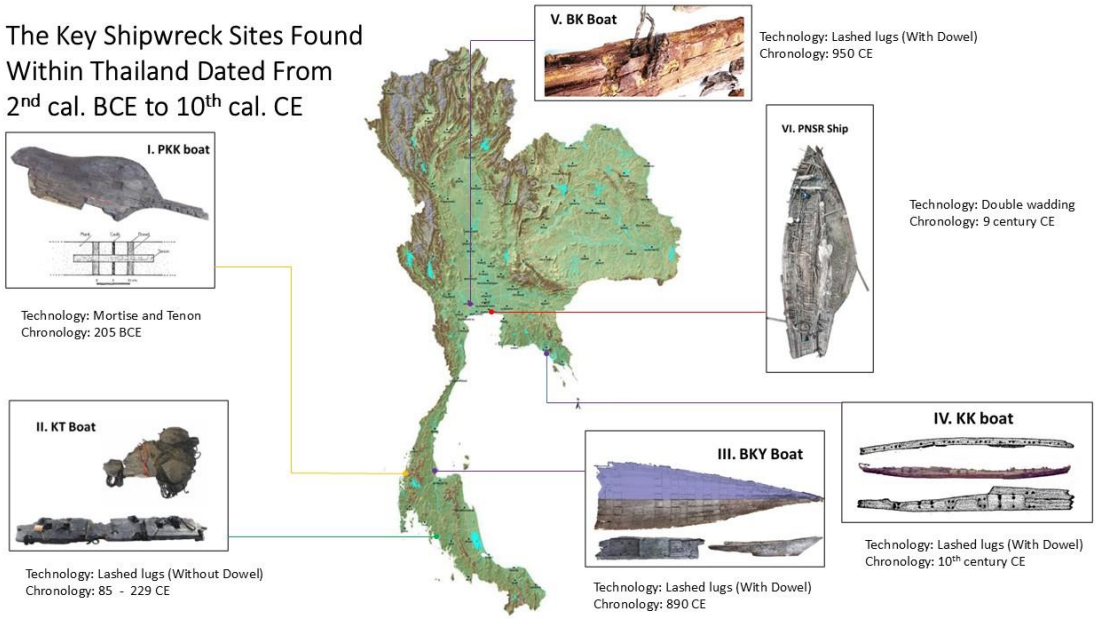

Figure 2. Key shipwreck sites found in Thailand, dating from the 2nd cal. BCE to the 10th cal. CE: (I) indicates the location of the PKK ship (dating to 205 BCE), which featured mortise-and-tenon joinery in its plank fastening; (II) indicates the location of the KT boat (dating to 85-205 CE), which featured lashed lugs (without dowels).

Figure 3. Plan of the PKK site before the 2019 excavation. The green grid indicates the location of the test pit (Ploymukda & Piromrak, 2019, p. 19).

In 2019, the UAD and FAD returned to the site and conducted a full-scale excavation with the purpose of recovering the timbers from the site and transporting them back to the UAD office in Chanthaburi for conservation. The author performed a Ground Penetrating Radar (GPR) survey with support from an archaeologist from Silpakorn University. The GPR survey detected a 12 by 8 metres sub-surface anomaly oriented in an east-west direction. The team decided to establish a 40 by 20 metres excavation grid to fully cover the whole shipwreck area (Ploymukda & Piromrak, 2019, p. 12)

The excavation yielded 16 massive timbers and various artifacts. The recovered timbers consisted of hull planks assembled edge-to-edge (carvel-built) using locked mortise-and-tenon joints; a technique rarely seen in Southeast Asia. This method utilises hidden wooden tenons to bridge adjoining planks, which are securely locked in place by two wooden dowels or pegs. The joints are inserted entirely within the thickness of the wood, only the ends of the locking dowels are visible on the hull's surface (Ploymukda, 2020, p. 48).

The recovered hull planks vary in length, comprising both short and long timbers. Evidence of scarf joints was also identified, it indicates the method used for join planks longitudinally to extend their overall length. The individual planks measure between 35 and 40 cm in width and 10 cm in thick. Along their edges, mortises were cut measuring 10 cm in length, 2 cm in width, and 12 cm in depth, spaced at regular intervals of 30 to 50 cm.

The joints were secured by 2 cm predrilled holes that were drilled from the outboard to the inboard side, they aligned precisely with the center of each mortise and tenon. The wooden tenons measure 24 cm long, 10 cm wide, and 2 cm thick. Notably, the length of the tenon is exactly twice the depth of a single mortise (12 cm); thus, when assembled, the tenon fits perfectly within the adjoining mortises of two combined planks.

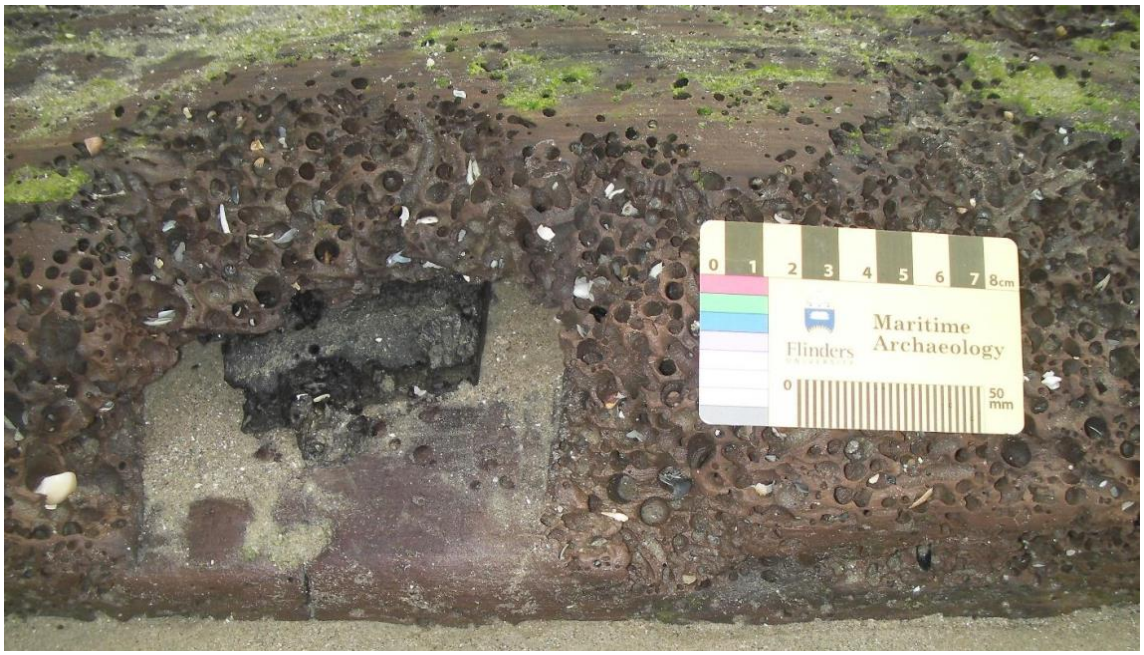

Figure 4. A fragment of a tenon fitted into a mortise, found on a timber of the PKK shipwreck (Ploymukda & Piromrak, 2019, p. 201).

To lock the joint, wooden dowels measuring 2 to 2.5 cm in diameter were inserted transversely from the exterior (outboard) of the hull through to the interior (inboard). Once driven tightly into place, the excess dowel material on both the inboard and outboard surfaces was trimmed flush with the plane of the hull planks. Because they were trimmed flush with the wood, the original, pre-cut length of the dowels remains unknown.

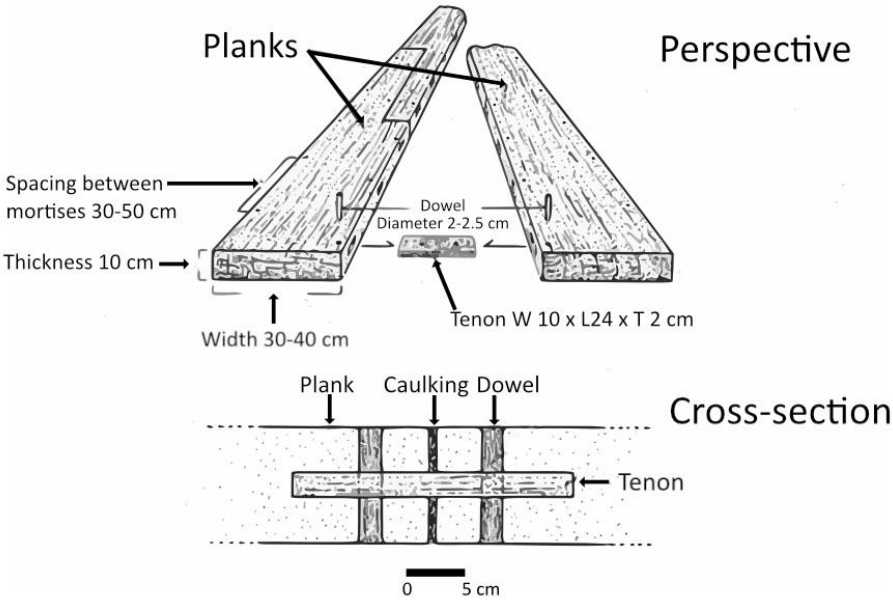

Figure 5. A locked mortise-and-tenon joint found on a timber of the PKK ship. This drawing was modified by the author from the original drawing, courtesy of Dacha Phonthai, Senior Surveyor at the UAD, Thailand.

The recovered ship components were collected and submitted to the Department of Forestry, Thailand, for wood species analysis. The results revealed that all the timber utilised in the vessel's construction originates from species native to Southeast Asia. The specific material identifications are as follows:

Planks: The hull planks were made from *Terminalia nigrovenulosa* Pierre, a species native to Southeast Asia (Nanakorn, 1985, pp. 87-90).

Tenons: The tenons were crafted from velvet tamarind, known locally in Thai as *Khleng* (*Dialium cochinchinense* Pierre), which is native to mainland Southeast Asia (Whitmore, 1973, p. 259).

Dowels: The locking dowels were crafted from teak, referred to in Thai as *Sak* (*Tectona grandis*), a species native to South and Southeast Asia (Verhaegen et al., 2010, p. 732).

Accelerator Mass Spectrometry (AMS) radiocarbon dating of the hull planks, conducted by the Beta Analytic laboratory (sample number: Beta 459734: UAD001), yielded a calibrated date range of 200-140 BCE (Ploymukda, 2020, p. 54). This chronological framework is further corroborated by relative dating based on artifacts recovered from both the shipwreck and nearby archaeological sites, specifically Bang Kluay Nok and Phu Khao Thong (Kangked, 2009, pp. 49-50). Consequently, the vessel is securely placed within the transitional proto-historical to early historical period of the Thai-Malay Peninsula.

Khlong Thom Shipwreck (KT)

Khlong Thom (KT) shipwreck was discovered along the banks of Khlong Thom (the Thom Canal in Thai). This waterway flows directly through the Khuan Luk Pad (KLP) archaeological site, located behind the Khlong Thom Temple in Khlong Thom Tai Subdistrict, Khlong Thom District, Krabi Province (Piromrak, 2019, p. 3). Khuan Luk Pad has been firmly identified as an early historical port settlement and has yielded a diverse array of artifacts. Notably, the site is recognised as a major bead production centre on the Thai-Malay Peninsula (Veeraprasert, 1985, p. 40-49). The canal provides direct maritime access from the Khuan Luk Pad site out to the sea, and the shipwreck itself was found in the specific section of the waterway that traverses this ancient settlement.

Figure 6. The location where the KT boat was found in the Thom canal, which runs through the KLP site in Krabi Province, Thailand. The red rectangular area indicates where the timbers were found, and the black dotted oval shows the location of the shipwreck (Piromrak, 2020).

Despite the Khlong Thom site pending full excavation, the existing samples of timber and rope definitively indicate a shell-based, edge-to-edge carvel vessel built with the "lashed-lug" technique. In KT boat, hull planks were custom-carved to retain raised inboard ridges, known as lugs. To bind the planks together, builders drilled L-shaped edge holes that aligned to create continuous U-shaped channels (Piromrak, 2023, p. 6), threading rope through them to stitch the hull segments securely. Tension was optimised by driving wooden wedges into these bindings. Finally, transverse frames were positioned across the raised lugs and lashed to the hull through U-shaped holes bored directly into the lugs, with the rope likewise tightened and locked using wedges (Piromrak, 2020, p. 35)

Twelve plank samples were recovered (widths: 24-28 cm, thicknesses: 3-4 cm; lengths: unknown). The rectangular lugs (30 × 20 cm, 3-4 cm thick) were carved directly from the plank timber and spaced approximately 40 cm apart (based on sample KT001). These lugs slope downward to overlap the lower planks and feature pre-carved holes for the frame lashings.

Frames were crafted from naturally curved, debarked timber, the surviving frame fragments are roughly cylindrical with a 12 cm diameter. Their original lengths cannot be determined due to breakage. The frames were secured to the lugs using black, two-strand plant-fiber rope (3.5-4 cm in diameter). The rope was tied in a three-loop crisscross ("X") pattern. Tapered, half-cylindrical, wooden wedges (12 × 3 cm) were driven tightly into the bindings to increase tension and lock the joints (Piromrak, 2019, 2020, 2023).

The recovered ship components were collected and submitted to the Department of Forestry, Thailand, for species analysis. The results revealed that the materials utilised in the KT vessel's construction originate from species native to Southeast Asia. The specific material identifications are as follows:

Planks: Crafted from *Hopea odorata* (Piromrak, 2020, p. 42).

Wedges: Made from *Mesua ferrea* L. (Piromrak, 2020, p. 41).

Rope: Made from the fiber of the sugar palm, *Arenga pinnata* (Piromrak, 2020, p. 32).

Caulking Material: The caulking found sealing the gaps between the planks was identified as *Payena acuminata* Pierre (Piromrak, 2020, p. 42).

Frames: The wood species used for the frame samples currently remains unidentified.

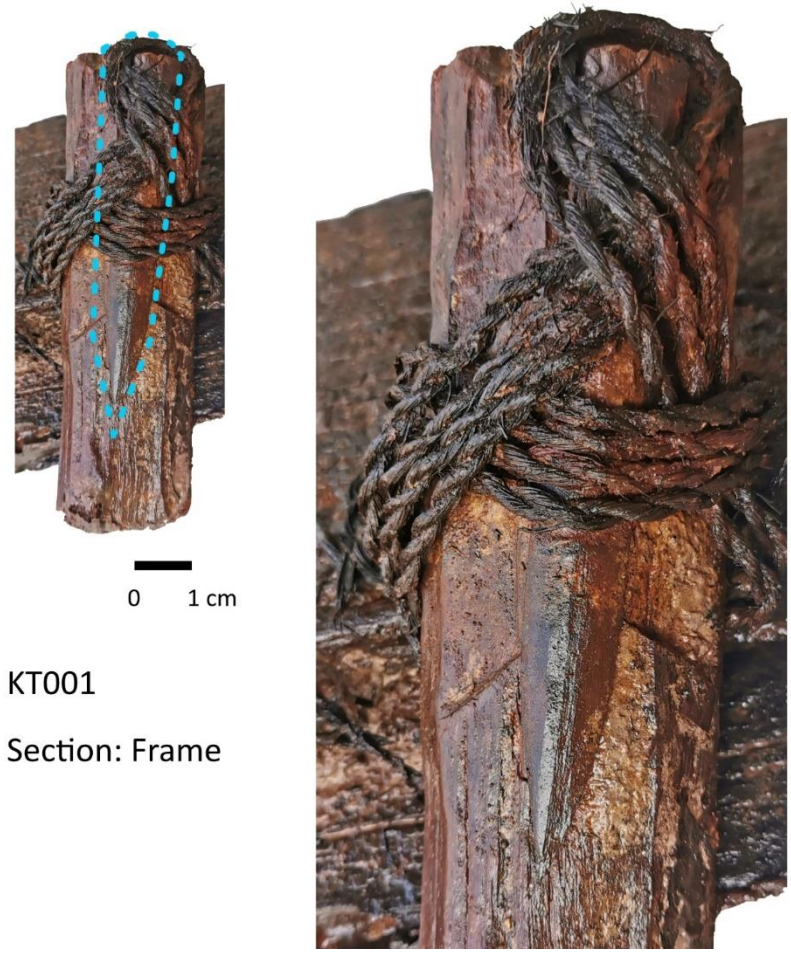

Figure 7. A frame of the KT boat lashed to the lug using rope and secured with a wedge.

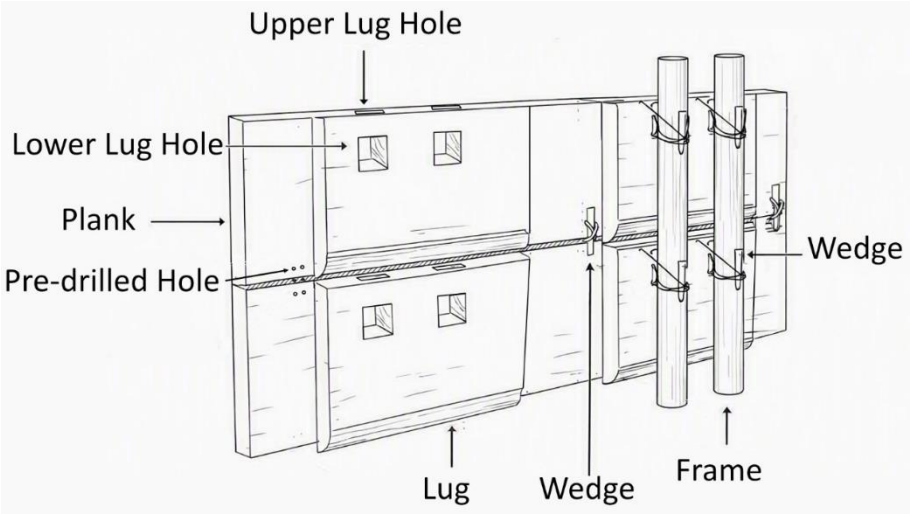

Figure 8. A reconstructed 3D model of the plank-fastening method found on a timber of the KT boat.

Figure 9. A fragment of a frame lashed to the lug of the KT001 plank using black, two-strand organic rope.

Discussion

Socio-cultural development during the proto-historical period in the Thai-Malay Peninsula was the result of both internal evolution and external cultural exchange facilitated by land and maritime interactions. Consequently, the Thai-Malay Peninsula emerged as a major cultural hub in Southeast Asia geographically. As previously noted, Southeast Asia became a node in the international maritime network by the first century CE due to its strategic location and rich resources. This connectivity is believed to have brought new people, technologies, and religions to the area, a process of cultural exchange that Cœdès termed "Indianisation" (Cœdès, 1975, p. 14). Contact with Rome and India dates back to the late first century BCE and paved the way for the region to adopt Indian social structures (Indrawooth, 2005, p. 94). As both internal and international trade flourished, coastal communities grew significantly to support these booming maritime networks (Saraya, 1989, p. 100).

The discovery of imported archaeological evidence serves as a strong indicator of this connectivity. Artifacts such as beads and stone inscriptions in the Tamil-Brahmi script found at the Khuan Luk Pad (KLP) and Khlong Thom (KT) sites, dating to the 2nd and 3rd centuries CE (Veeraprajak, 1986, p. 8), alongside Pallava script inscriptions dating to the 6th century CE found across the Thai-Malay Peninsula, highlight the region's significant cultural development. This evolution was heavily driven by maritime interactions and the assimilation of cultures from outside the region.

Similarly, shipwreck such as the Pak Khlong Kluay (PKK) shipwreck is inherently recognised as a vital piece of evidence for cross-cultural maritime interaction (Kimura, 2022, p. 100). Beyond the vessel's mere presence, the author believes that analysing its specific construction techniques provides crucial insights into the introduction of innovations, cultural transmission, and independent socio-cultural development within the Thai-Malay Peninsula.

The locked mortise-and-tenon technique found on the PKK shipwreck is well-documented in the Mediterranean, Egypt, and Europe, but it remains rare in Southeast Asia. As of 2026, regional parallels are limited to two contemporary boat burials in Vietnam (Bellwood et al., 2007, p. 2). However, a contemporary Chinese shipwreck offers similarities in this shipbuilding practice, featuring comparable dimensions such as 10 cm-thick planks and 12 mm wooden dowels (Weiqiao Archaeological Team, 2015, p. 965).

In the Mediterranean, this technique dates to the Late Bronze Age (Whitewright, 2017, p. 205). Prominent examples include the Uluburun shipwreck (Türkiye, 1320-1295 BCE), featuring mortises spaced 24-26 cm apart (Pulak, 1998, pp. 210-213), and the 4th-century BCE Kyrenia ship, which utilised closely spaced mortises at 10 cm intervals (Steffy, 1985, pp. 71-84).

Egyptian evidence extends even further back, observed at the superstructure of Khufu I ship (2550 BCE) and the Mataria riverboat (500 BCE) (Ward, 2004, p. 14). Iconographic records, such as 5th-Dynasty tomb reliefs at Saqqara, even depict shipwrights actively chiseling these specific edge slots (Mahran, 2013, p. 53). Furthermore, the 3rd century BCE Marsala Punic warship in Sicily demonstrates that this joinery was not limited to merchant vessels, but was also integral to ancient military naval architecture (Whitewright, 2017, p. 207).

While the locked mortise-and-tenon technique is well-documented in the Mediterranean and Egypt, its rarity in Southeast Asia strongly indicates cross-cultural contact (Kimura, 2022, p. 100; Weiqiao Archaeological Team, 2015, p. 963) and technological transfer (Bellwood et al., 2007, p. 19). Although Chinese Neolithic societies used this joinery in architecture 3,500 years before the Phoenicians applied it to boat-building in the Mediterranean, Bellwood argues that its maritime application in ancient Southeast Asia (such as in 1st-century BCE Vietnam) was likely introduced from the Mediterranean via India (Bellwood et al., 2007, p. 19).

The author partly supports this framework. As technological transfer involves more than just copying mechanics; it requires deep material knowledge and adaptation to local environments and economies (Adams, 2013, p. 23). The PKK shipwreck exemplifies this. Its massive, entirely local material procurement proves the vessel was constructed within Southeast Asia.

Crucially, the shipwrights possessed profound local botanical knowledge, purposely selecting specific regional woods to perfectly replicate the Mediterranean tradition of using planks softer than tenons (Whitewright, 2017, p. 204). They crafted the hull planks from *Terminalia nigrovenulosa* (hardness: 1,000 kg) and the tenons from significantly harder *Dialium cochinchinense* Pierre (hardness: 1,920 kg) (Chulruek et al., 2005, p. 26), this demonstrates that the shipwrights were highly skilled and possessed an exceptional understanding of material selection. They had mastered this mortise and tenon shipbuilding technology while adhering to Mediterranean structural traditions. Furthermore, the construction of the PKK vessel reflects the substantial economic resources of its owner. The complete ship was successfully launched and used meet specific purpose and environmental needs until its eventual abandonment.

Furthermore, the recovered artifacts and the location where it sank indicate the vessel was an open-sea cargo ship. While this aligns perfectly with Bellwood's proposal of maritime technological transfer, the author posits that independent regional development remains a highly plausible alternative.

Pegged mortise-and-tenon joinery appears globally across vastly disjointed timelines, from Neolithic China and Egypt (2500 BCE) to Polynesia (1500 BCE), the Late Bronze Age Mediterranean, and 2nd-century BCE Southeast Asia (Bellwood et al., 2007, p. 19). Given this scattered chronology and the lack of comprehensive studies tracing the evolution lineage of the technique, it is impossible to definitively prove that it spread solely through cultural transmission. Thus, independent technological development within the Thai-Malay Peninsula cannot be entirely ruled out. As evidence of this capacity for local innovation, Southeast Asian shipwrights possessed the resources and local expertise to develop their own maritime technologies, most notably the "lashed-lug" tradition. Found across Mainland and Island Southeast Asia, these vessels feature carved inboard protrusions (*tambuku*) used to lash transverse frames to the hull (Alcina et al., 1975; Horridge, 1982; Lacsina, 2015, 2016; Manguin, 2019). Furthermore, rather than a true structural keel, the vessel utilised a keel-plank that connected to wing structures at both ends to accommodate its double-ended hull. Researchers trace the evolution of these ships by analysing lug morphology, joinery techniques, and dowel usage (Horridge, 1982; Liebner, 2014; Noriko et al., 2014; Lacsina, 2015, 2016; Mochtar, 2018; Manguin, 2019; Piromrak, 2020, 2023; Rahothan & Vosmer, 2023).

Manguin classifies early lashed-lug vessels, such as Malaysia's Pontian boat, by their reliance on rope and wooden dowels for plank joinery (Manguin, 2019, p. 404). He also places Thailand's Khuan Luk Pad (KLP) boat (5th-7th centuries CE) within this earliest group. The KLP vessel features trapezoidal and semi-circular lugs with pre-carved lashing holes, but it notably lacks evidence of dowels for edge-to-edge planks joinery (Manguin, 2019, p. 402). Instead, adjoining planks were stitched together using L-shaped edge holes that aligned to form internal U-shaped channels. This engineering allowed the rope to bind the hull from the inside without ever penetrating the outboard surface.

During the 3rd to 5th centuries CE, edge dowels were introduced alongside rope stitching for plank joinery. Rahothan and Vosmer (2023, p. 7) trace an evolution from early vessels lacking dowels, the ships equipped with single dowels between lashings (such as Malaysia's Pontian boat), and eventually to those with multiple dowels. However, Thailand's KT boat (85-229 cal CE) complicates this timeline; despite its lug configuration mirroring the KLP and Pontian vessels, it completely lacks edge dowels and relies exclusively on rope (Piromrak, 2023, p. 6).

From the 7th century CE onward, lugs became distinctly rectangular in cross-section. Crucially, the large rectangular lashing holes carved directly through earlier lugs were replaced by four smaller, L-shaped holes bored into the lug edges. The author posits that this morphological shift was specifically intended to increase the structural strength of the frame-to-hull bindings. Concurrently, vessels like the Sambirejo began incorporating counter-pinned mortise-and-tenon joints to further secure the planks (Manguin, 2019, p. 407), reflecting ongoing regional structural evolution.

In the later tradition, rope stitching for hull planks was abandoned entirely in favour of edge dowels; rope was retained only for lashing frames to the lugs. The Cirebon (Indonesia) and Butuan (Philippines) shipwrecks (No. 1 and 5) exemplify this shift (Liebner, 2014; Manguin, 2019). Without the stitched planks, Butuan builders drove counter-pins directly through the embedded edge dowels (Manguin, 2019, p. 403; Rahothan & Vosmer, 2023, p. 8). The author hypothesises that this pinning technique was developed to compensate for the structural strength lost by abandoning rope stitching. Despite these overarching trends, these vessels remained highly individualised, with each ship exhibiting unique variations in plank, dowel, and lug configurations (Lacsina, 2016, p. 206).

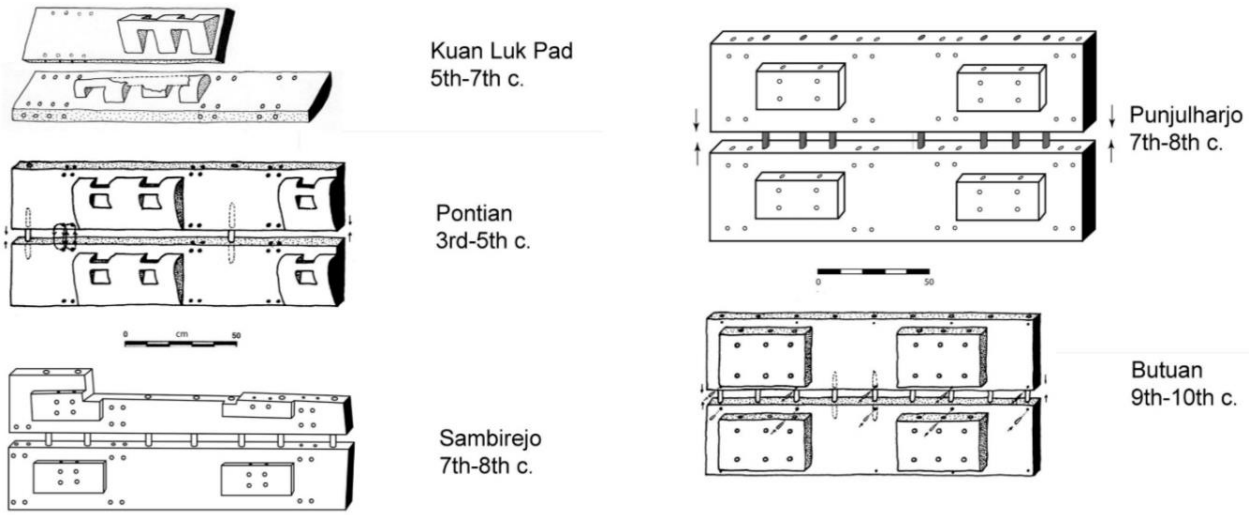

Figure 10. A drawing illustrating the evolution of lashed lugs, presented by Manguin (Manguin, 2019, p. 402).

The Southeast Asian lashed-lug tradition evolved over centuries to meet diverse maritime needs. Consequently, the author posits that Manguin's joinery-based evolutionary framework has limitations. The joined planks alone does not fully define a tradition of the vessel. Environmental demands, material availability, and specific operational purposes were equally influential in shaping these ships. Broadly, the regional Southeast Asian shipbuilding tradition is characterised by ironless construction, protruding lugs, frame lashings, plank lashings (in the early and middle stages), edge dowels (in the later stage), keel-planks, and double-ended hulls. Other techniques, such as mortise-and-tenon joinery, did not vanish entirely; their appearance in later vessels (e.g., Butuan 2, Sambirejo) shows continued (Lacsina, 2016, p. 113; Manguin, 2019, p. 407), albeit limited use without ever becoming a dominant regional tradition.

Lacsina highlights this complexity, noting that defining Southeast Asian shipbuilding traditions sparks debate over whether a "tradition" should be viewed as a static concept or a dynamic technological evolution (Adams, 2013; Lacsina, 2016, p. 206; Muckelroy, 1974). This debate is particularly relevant here; because the evolutionary framework of Southeast Asian shipbuilding remains fluid, pinpointing the exact intersections of technology, material, environment, and purpose is difficult. Nevertheless, actively analysing these variables is crucial to truly understanding the socio-cultural dynamics of the maritime communities that built and utilised these ships (Adams, 2013, pp. 28-33).

Ultimately, observing beyond the pure narrative of shipbuilding technology to the broader socio-cultural development of the Thai-Malay Peninsula, it can be posited that both the adaptation of external knowledge and independent local innovation are highly plausible. Notably, vessels featuring mortise-and-tenon fastening techniques and the lashed-lug tradition appeared in the Thai-Malay Peninsula during the proto-historical period. This confirms the early presence of advanced shipbuilding technologies that had already been adapted to meet the specific needs of local maritime communities.

Conclusion

The historical and archaeological evidence from the Thai-Malay Peninsula reveals a highly integrated and dynamic maritime landscape during the proto-historical period. As the region transitioned into a focal point for global exchange, its coastal communities, which were also known as ports, engaged in extensive cross-cultural exchange, evidenced by the widespread distribution of imported ceramics, beads, and inscriptions. However, the most relevant materials regarding the socio-cultural development and technological sophistication in the region lie in its maritime construction.

The analysis of the Pak Khlong Kluay (PKK) and Khlong Thom (KT) shipwrecks demonstrates that Southeast Asian shipwrights were highly adaptable and possessed profound indigenous expertise. The PKK vessel illustrates that regional builders did not simply copy designs; they actively adapted mortise-and-tenon technology and tradition by deliberately selecting specific local hardwoods and softwoods to fulfill specific structural requirements. Concurrently, the KT vessel underscores the vitality of the indigenous lashed-lug tradition, an entirely distinct structural paradigm engineered to navigate the specific environmental realities of Southeast Asian waters.

As this study highlights, attempting to classify Southeast Asian shipbuilding into a rigid, linear evolutionary framework based solely on joinery techniques is insufficient. A vessel's morphology and construction were equally dictated by environmental demands, material availability, economics, ideology, and specific operational purposes (Adams, 2013, pp. 24-27). Ultimately, the proto-historical communities of the Thai-Malay Peninsula

were not only passive recipients of external overseas influence. Through a simultaneous process of cross-cultural technological transfer and independent local innovation, they developed advanced, highly individualised maritime technologies that successfully sustained the earliest networks of global transoceanic trade.

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