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Wood utilization and cultural integration indicated by woodware excavated from ancient Turpan, Xinjiang

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Gaochang, ancient Turpan, had a unique geographical environment and historical characteristics of multi-ethnic integration of humanities. Since the Han Dynasty, a large number of central plains people settled here, integrating multi-culture into Gaochang. In the present study, 6 tree species were identified from 11 wood samples of cemeteries of the ancient city of Gaochang (Astana, Badam, and Badam Eastern Cemeteries), including *Salix* sp. (36.36%), *Populus* sp. (27.27%), *Ulmus* sp. (9.09%), *Symplocos* sp. (9.09%), *Photinia* sp. (9.09%), and *Picea* sp. (9.09%). Local wood of *Salix*, *Populus*, and *Picea* was frequently used in daily life. However, wooden artefacts of *Symplocos*, *Photinia*, and *Ulmus* were brought to Gaochang through the Silk Road. Moreover, the custom of burying wooden figurines and hand-held wood originated from the Central Plains and mixed with the local characteristics of Gaochang. Therefore, the ancestors of Gaochang developed wood utilization suiting local conditions and promoted the multicultural integration in Xinjiang.

Turpan, called Gaochang in ancient times, is the hub of the world-famous Silk Road in the Xinjiang region. The history of Gaochang can be divided into 5 periods: Gaochang Rampart (21 BC-AD 327), Gaochang Prefecture (AD 327-460), Gaochang Kingdom (including Kan's, Zhang's, Ma's, and Qu's Gaochang Kingdoms; AD 460-640), Xizhou (AD 640-791), and Gaochang Uighur Kingdom (AD 866-1280). Dating back to the first year of Chuyuan (48 BC) of the Western Han Dynasty, military and civilians from the Central Plains of China were sent to Gaochang to defend border areas and open up wasteland[1]. During the Wei, Jin, Southern and Northern Dynasties (AD 220-589), civilians suffered from the war and migrated westward intermittently, making Gaochang a multi-ethnic and multi-cultural integration area[2,3]. According to the analysis of the discovered Turpan documents, the Han ethnic group took up 70–75% of the population of Gaochang Kingdom (AD 460-640), leaving 25-30% for the other ethnic groups[4].

Farming culture from the Central Plains and nomadic culture from Northern Grassland, Central Asia, and West Asia also had influence on the Gaochang civilization during the cultural exchange[5–10]. Therefore, Gaochang, which was located on oasis district of Turpan Basin[11,12], possessed a unique natural environment and diverse culture background[13,14]. Its compound cultural accumulation reflected in wood utilization as well, showing characteristics of wide material selection range and targeted wood using strategy. According to existing research (e.g., Yanghai, Jiayi, and Shengjingdian Cemeteries, etc.), woods of *Salix*, *Populus*, *Lonicera*, *Tamarix* from Turpan Basin and *Picea* from distant Tianshan Mountains were typical common wood material[15,16]. To meet requirements for special applications, pliable woods of *Morus* and *Lonicera* were suitable for making bows[17] and porous woods like *Clematis* were used as fire-making tools[18]. Overall, wood played an important role as daily necessities, burial accessories, tools, building components, weapons, etc. (Fig. 1).

However, the prehistoric civilization was put into a sharper focus, while the historical period received less attention. Fortunately, the discovery of cemeteries of the ancient Gaochang City during the Jin to Tang dynasties (AD 266-907) offered the chance to explore the unknown cultural carrier and connotation. Particularly, a large number of archaeological materials were excavated in the Astana, Badam, and Badam Eastern Cemeteries. Due to the dry environment of Turpan[19], many wood remains were well preserved. In this research, the wood genera and even species of wooden crafts will be identified to reconstruct ancient vegetation types and the ecological environment. According to the traditional customs, the deceased were treated as living persons. The results may be helpful to explain the lifestyle and cultural integration underlying the wood utilization mode of immigrants settled in Gaochang.

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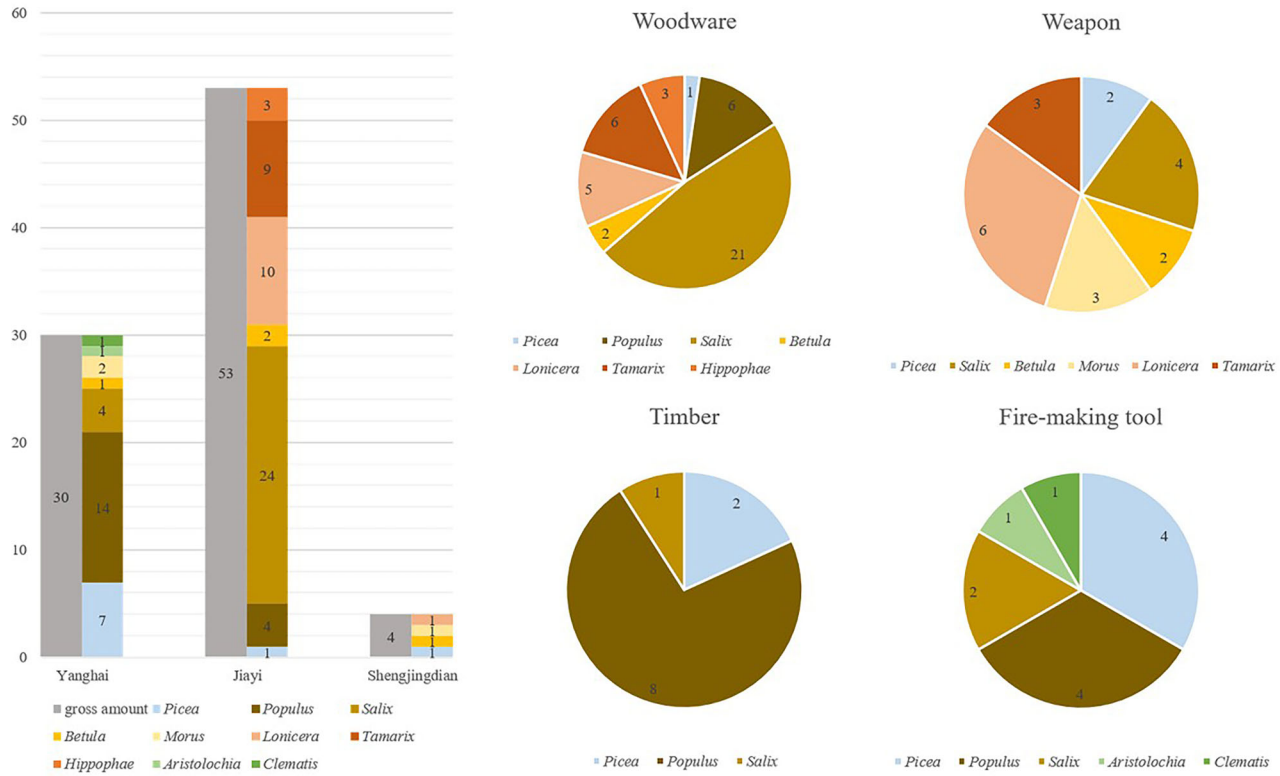

Fig. 1 | Quantity of desiccated wood remains of different tree species excavated from Yanghai (1260 BC-AD 200), Jiayi (850-350 BC), and Shengjingdian (250-100 BC) Cemeteries[15–18].

Methods

The Archaeological Context

Turpan City (42°15'10"~43°35' N, 88°29'28"~89°54'33" E) is located in the middle of the Turpan Basin. Because of the surrounding mountains like Bogda Mountains (Northern Tianshan Mountains) to the north and Jueluotage Mountains (Eastern Tianshan Mountains) to the south, this region belongs to continental desert climate in warm temperate zone with low rainfall (8~25 mm/year), high evaporation (2520~3167 mm/year), big temperature difference, and frequently gale-force winds. The annual mean temperature, mean July temperature, and mean January temperature are respectively 14.3 °C, 32.2 °C and −7.9 °C[2]. The main vegetation type in this area is semi-shrub desert vegetation, which primarily consists of *Scorzonera divaricata* and *Alhagi sparsifolia*[20].

The Flaming Mountains, a foothill of the Bogda Mountains, lie in central Turpan Basin. The Gaochang Ruins lie in the southern foot of the Flaming Mountains. Some archaeologists conjectured that the ancient city of Gaochang was first built during the period of Gaochang Prefecture (AD 327-460). According to the radiocarbon dating results, it was determined that the ancient city of Gaochang was in use from the beginning to the period of the Gaochang Uighur Kingdom (AD 866-1280)[21]. Most of the residents were buried within a 5-kilometre radius north of the ancient city of Gaochang after death, which formed an east-west oriented, intermittently connected, and family-buried cemetery group (Fig. 2)[22]. After the abandonment of Gaochang City in the late 13th century AD, the newly built Karakhoja Village divided the cemetery group into two parts. The eastern part was called Karakhoja Cemetery, while the western part was called Astana Cemetery[23].

The Astana Cemetery was a public cemetery for officials and civilians in Gaochang[24], covering an area of about 10 km^2. This cemetery was discovered in 1898, and there were more than 500 extant tombs. Since 1959, over 400 tombs have been excavated, and brought to light tens of thousands of cultural relics (e.g. documents, epigraphs, silk fabrics, etc.) as well as many mummies[23]. The time span of Astana Cemetery was from the Jin to the prosperous Tang Dynasty (AD 266-755)[25]. Not only the Hans, but also the Jushis, the Huns, and the Sogdians were buried in their own family tombs. Here also lay the remains of several prominent local figures, such as Juqu Fengdai (the governor of Gaochang Prefecture) and Zhang Xiong (the prestigious left guard general of Qu's Gaochang Kingdom). As the cemetery with the largest number of excavated tombs and cultural relics from the Jin to Tang Dynasties, the Astana Cemetery had great significance for improving the archaeological and cultural sequence of historical periods and enriching local history research in Xinjiang.

Badam and Badam Eastern Cemeteries belonged to Karakhoja Cemetery, which showed a high similarity in funeral customs to the Astana Cemetery. The former mainly buried residents from Chonghua Township, and most of the tombs dated back to the period of Gaochang Kingdom (AD 460-640) as well as three tombs of the period of Xizhou (AD 640-791) during the Tang Dynasty. The latter buried officials of the period of Xizhou during the Tang Dynasty, including Cheng Huan, the deputy supervisor of Beiting Supervisory Office[21,26]. The occupants of tombs besides the Hans included the Kuchean, the Indians, and the Sogdians. In addition, numerous precious cultural relics were unearthed, such as Fuxi and Nuwa silk paintings, bronze mirrors with interlocking grape branch design, Pseudo-Roman gold coins, and Persian silver coins with Shaman pattern[27]. It was a rare glimpse into the exchanges among cultures of different nationalities.

Materials and methods

There are 10 wooden artefacts and 1 desiccated wood sample studied in this research, and each of them was damaged to various degrees. These wooden artefacts include 2 wooden figurines, 2 wooden bowls, 2 wooden combs, 1 butt plug, 1 lacquered wooden plate, 1 hand-held wood, and 1 eared cup (Fig. 3). The desiccated wood sample was collected from the outer coffin (Fig. 4). In order to minimize the damage to these wooden artefacts, wood splinters or blocks from each wooden artefact were gathered for analysis.

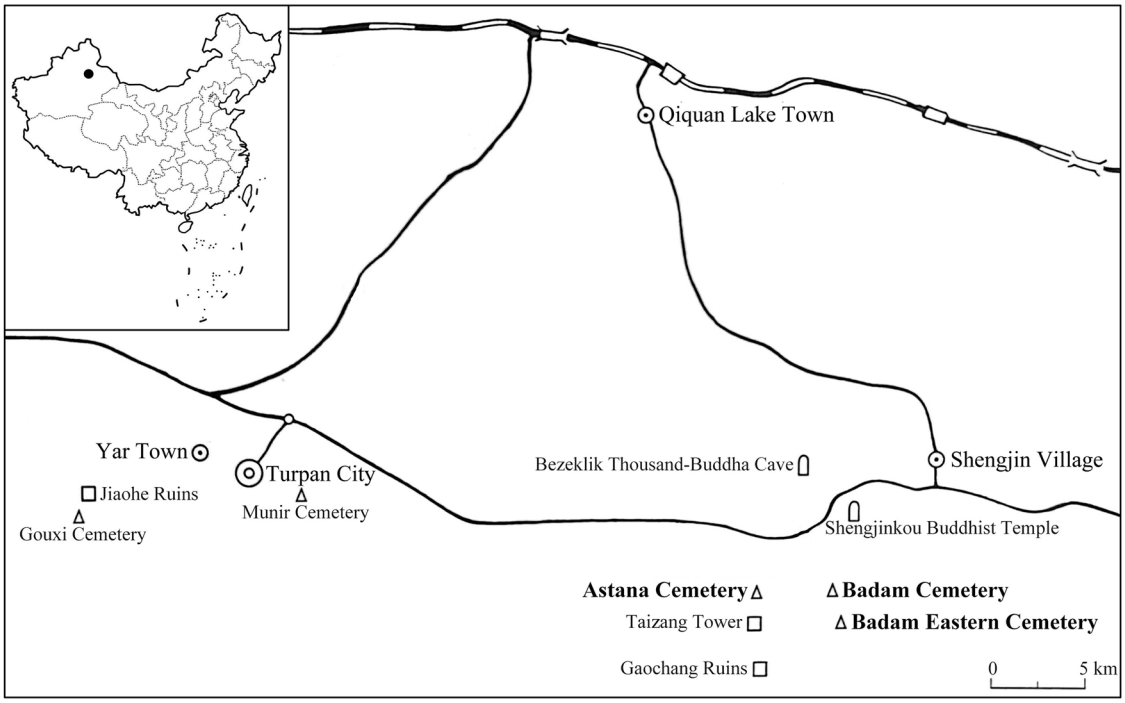

Fig. 2 | Location map of Astana, Badam, and Badam Eastern Cemeteries[22,26].

Three sections of samples, namely, transverse section, radial section, and tangential section, were trimmed by double-sided blades. The hand-sliced method was adopted to cut samples into slices. The thermal scientific Phenom Pro X scanning electron microscope (SEM) was used to observe the microstructure of slices in three sections. However, most of the samples were too dry to cut into slices. So, these were prepared for identification using traditional methods. They were first cut into small blocks. Then, they were boiled in water and subsequently embedded in polyethylene glycol at a temperature of 60 °C for 2 days. Finally, 15 μm-thick sections were cut on a sliding microtome to produce three sections. After this, the slices were stained with a 4% solution of safranin. The thin, stained sections were studied using a microscopic image analyzer (BX60) with a DP72 digital collector.

Wood structural characteristics of three sections were compared with modern ones recorded in references such as *Anatomical Database and Atlas of Chinese Woods*[28], *Atlas of Chinese Woods*[29], and *IAWA list of microscopic features for softwood/hardwood identification*[30,31], for identifying the families and genus of wood samples.

Results

The identification results

A total of 11 wood samples were identified (Table 1, Figs. 5, 6), including *Salix* sp. (36.36%), *Populus* sp. (27.27%), *Ulmus* sp. (9.09%), *Symplocos* sp. (9.09%), *Photinia* sp. (9.09%), and *Picea* sp. (9.09%). The specific microstructural features are described below.

Populus sp. Growth rings: Boundaries are distinct. Vessels: Wood diffuse-porous to weakly semi-ring-porous. Vessels solitary or in radial multiples of 2-3; solitary vessel outline angular. Perforation plates are simple. Intervessel pits alternate, shape of the pits polygonal, size of the pits 7-10. Vessel-ray pits with much reduced borders to apparently simple: pits are rounded or angular. Vessel-ray pits are restricted to marginal rows. Mean tangential diameter of vessel lumina 50-100 μm; vessels/mm^2 ≥ 100. Tracheids and fibres: Fibres with simple to minutely bordered pits. Non-septate fibres present. Fibres thin-walled. Axial parenchyma: Extremely rare or in marginal bands; four (3-4) or eight (5-8) cells per parenchyma band. Rays: Exclusively uniseriate. Rays homocellular; all ray cells procumbent. Rays/mm 7-12.

***Ulmus* sp**. Growth rings: Boundaries are distinct. Vessels: Wood ring-porous. Vessels in tangential bands and clusters are common. Perforation plates are simple. Intervessel pits alternate, shape of the pits polygonal, size of the pits 7-10 μm. Vessel-ray pits with distinct borders; similar to intervessel pits, or with much reduced borders to apparently simple: pits rounded or angular. Helical thickenings are present throughout the body of the narrower vessel elements. Mean tangential diameter of vessel lumina 100-200 μm in earlywood. Tracheids and fibres: Vascular tracheids present. Fibres with simple to minutely bordered pits. Non-septate fibres present. Fibres thin- to thick-walled. Axial parenchyma: Diffuse, scanty paratracheal, vasicentric and in marginal bands; two or four (3-4) cells per parenchyma strand. Fusiform parenchyma cells present. Rays: Width 1 to 7 cells. Larger rays commonly 4- to 7-seriate. Rays of two distinct sizes. Rays homocellular, all ray cells procumbent. Rays/mm 5-7.

***Picea* sp**. Growth rings: Boundaries are distinct. Transition from earlywood to latewood is gradual. Tracheids: Tracheid pitting in radial walls is predominantly uniseriate. Latewood tracheids thin-walled. Torus present. Axial parenchyma: Absent. Rays: Exclusively uniseriate. Average ray height: medium (5 to 15 cells). Fusiform rays present; 250 to 600 μm high. Ray tracheids are commonly present; helical thickenings are rarely present. The cell walls of ray tracheids are smooth. Ray tracheid pit borders are angular. End walls and horizontal walls of ray parenchyma cells are distinctly pitted. Transverse end walls are beaded or nodular. Indentures present. Cross-field pitting piceoid or cupressoid; number of pits per cross-field mostly 1-3. Intercellular canals: Axial and radial resin canals present with mostly thick-walled epithelial cells.

***Salix* sp**. Growth rings: Boundaries are distinct. Vessels: Wood diffuse-porous. Vessels in diagonal and/or radial pattern. Vessels solitary or in radial multiples of 2-3; solitary vessel outline angular. Perforation plates are simple. Intervessel pits alternate; size of the pits 4-7 μm. Vessel-ray pits with much reduced borders to apparently simple: pits are rounded and mostly restricted to marginal rows. Mean tangential diameter of vessel lumina 50-100 μm; vessels/mm^2 80-100. Tracheids and fibres: Fibres with simple to minutely bordered pits. Fibre pits are restricted to radial walls. Non-septate fibres present. Fibres are very thin-to

Fig. 3 | Wooden artefacts excavated from Astana and Badam Cemeteries (*Scale bars* in a-j are 1 cm). **a** Wooden figurine (72TAM173:7), **b** Butt plug (73TAM198:21-1), **c** Wooden figurine (73TAM206:23-3), **d** Lacquered wooden plate (73TAM505:2), **e** Hand-held wood (73TAM514:013), **f** Eared cup (06TAM605:17), **g** Wooden comb (04TBM203:9), **h** Wooden bowl (04TBM207:13), **i** Wooden bowl (04TBM207:15), **j** Wooden comb (04TBM216:5).

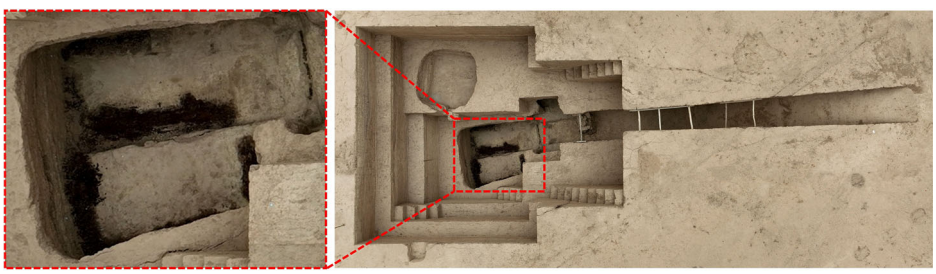

Fig. 4 | The outer coffin of M12 of Badam Eastern Cemetery. left The wooden outer coffin, right Top view of M12 of Badam Eastern Cemetery.

thin-walled. Axial parenchyma: Extremely rare and in marginal bands of one cell wide; eight (5-8) cells per parenchyma strand. Rays: Exclusively uniseriate. Rays heterocellular; body ray cells procumbent with one row of upright and/or square marginal cells. Rays/mm 9-12.

***Symplocos* sp.** Growth rings: Boundaries are distinct. Vessels: Wood diffuse-porous. Vessels are exclusively solitary; solitary vessel outline is angular. Perforation plates scalariform, with 20-40 or more bars. Intervessel pits are scalariform or opposite, size of the pits is 4-7 μm. Vessel-ray pits with distinct borders, or with much reduced borders: pits horizontal. Helical thickenings are present throughout the body of the vessel elements. Mean tangential diameter of vessel lumina ≤50 μm; vessels/mm^2 > 100. Tracheids and fibres: Fibres with distinctly bordered pits. Fibre pits are common in both radial and tangential walls. Non-septate fibres present. Fibres thin-to-thick-walled. Axial parenchyma: Diffuse, diffuse-in-aggregates, and scanty paratracheal, four (3-4) or

Table 1 | Specific information and identification results of wooden artefacts and a desiccated wood sample[23,25–27,84,97–101]

Cemetery	Number	Type	Dimension	Ages	Occupants	Excavated documents	Family	Genus
Astana	72TAM173:7	Wooden figurine	12.2 cm long	AD 501-640	One male and one female	-	Salicaceae	*Populus*
	73TAM198:21-1	Butt plug	13.3 cm long	AD 640-791	-	-	Salicaceae	*Salix*
	73TAM206:23-3	Wooden figurine	23.5 cm long	~AD 633-688	Zhang Xiong and his wife Qu	The epitaph of Zhang Xiong (AD 584-633) and his wife Qu (AD 607-688)	Salicaceae	*Salix*
	73TAM505:2	Lacquered wooden plate	2.7 cm high, 23 cm in lip diameter, 20 cm in bottom diameter	AD 640-791	Zhang Dinghe (the eldest son of Zhang Xiong)	-	Ulmaceae	*Ulmus*
	73TAM514:013	Hand-held wood	9.8 cm long	AD 501-640	One male and one female	-	Salicaceae	*Populus*
	06TAM605:17	Eared cup	3.6 cm high, 9.7×4.3 cm lip, 4.4×1.6 cm bottom	~AD 375	Chun and his wife Kui Tianying	The list of burial clothes of Kui Tianying in the fifth year of Xian'an (AD 375)	Salicaceae	*Salix*
Badam	04TBM203:9	Wooden comb	8.4×6.7×0.75 cm	AD 501-791	One male and three females (Kang clan)	-	Symplocaceae	*Symplocos*
	04TBM207:13	Wooden bowl	5.3 cm high, 8 cm in lip diameter, 5.3 cm in bottom diameter	~AD 680	One male (Kang clan)	The dispatch in the third year of Yifeng (AD 678) The records in the third year of Shangyuan (AD 676), the third year of Yifeng, and the second year of Tiaolu (AD 680)	Salicaceae	*Populus*
	04TBM207:15	Wooden bowl	7.6 cm high, 17.4 cm in lip diameter, 10.2 cm in bottom diameter				Salicaceae	*Salix*
	04TBM216:5	Wooden comb	6.1×5.6×0.8 cm	AD 501-791	One male and two females (Kang clan)	-	Rosaceae	*Photinia*
Badam Eastern	M12	Outer coffin	-	AD 640-791	-	-	Pinaceae	*Picea*

eight (5-8) cells per parenchyma strand. Rays: Width 1 to 3, occasionally 4 cells. Rays heterocellular; body ray cells procumbent with 2-4 or over 4 rows of upright and/or square marginal cells (Kribs types heterogeneous I or II). Rays/mm 15-20.

***Photinia* sp**. Growth rings: Boundaries are distinct to indistinct. Vessels: Wood diffuse-porous. Vessels are exclusively solitary; the solitary vessel outline is angular. Perforation plates are simple. Intervessel pits alternate, shape of the pits polygonal, size of the pits 6-8 μm. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape. Mean tangential diameter of vessel lumina ≤50 or 50-100 um; vessels/mm^2 ≥ 100. Tracheids and fibres: Fibres with distinctly bordered pits. Fibre pits are common in both radial and tangential walls. Non-septate fibres present. Fibres thin- to very thick-walled. Axial parenchyma: Diffuse and diffuse-in-aggregates; two, four (3-4) or eight (5-8) cells per parenchyma strand. Prismatic crystals are common in chambered axial parenchyma cells. Crystals are present in enlarged axial parenchyma cells. Rays: Width 1 to 3(4) cells. Rays heterocellular; body ray cells procumbent with 1-4 rows of upright and/or square cells (Kribs types heterogeneous II or III). Rays/mm≥12.

Tree species selection

Salix and *Populus* were common tree species in Xinjiang, and various funeral objects like woodware, grave goods, fire-making tools, weapons and even timbers for construction were made of both woods by the indigenous people. For this reason, both woods were widely unearthed in the Yanghai Cemetery (Turpan; 1260 BC-AD 200)[15,17,18,32], Jiayi Cemetery (Turpan; 850-350 BC)[16,17] and Ji'erzankale Necropolis (Tashkurgan; ~550 BC) in Xinjiang[33,34]. In addition, charcoals of *Salix* and *Populus* were discovered in the Adunqiaolu site (Wenquan; 1870-1574 BC)[35] and the Keyakekuduke military watchtower site (Yuli; AD 620-695)[36], which demonstrated these two tree species were also used as fuelwood. The wooden artefacts identified as *Salix* and *Populus* in this paper further confirmed that they were highly likely to be the dominant species or constructive species in Turpan at that time. The wood of *Populus* and *Salix* is very suitable for handcrafting because of its characteristics of low hardness, fine texture and well-distributed[29]. As a result, they can be made into different shapes and dimensions for different purposes. It is worth mentioning that branches of *Salix* are also used for weaving or making slender wooden artefacts due to the additional advantages of toughness and easy processing. Therefore, branches of *Salix* were excavated in the usage types of arrow shafts, self-bows[17], sticks, hand drills, crutches[33,34].

Lop Nur, as the water collection and salt accumulation centre of Tarim Basin, is bordered by Turpan to the north. There used to be an arid period, which resulted in plant adaptations to the environments of drought and saline[37]. It was consistent with the discovery of only *Populus euphratica* with drought-resistance and salt tolerance in Xiaohe Cemetery (2030-1590 BC)[38], Gumugou Cemetery (~1950 BC)[39], and Loulan Kingdom (202 BC-AD 58)[40,41]. Nevertheless, charcoals of *Salix* rather than *Populus* were unearthed from the ancient Dahe City site (AD 618-907; Barkol)[42]. The growing environment of hygrophilous *Salix* was relative humid[29], which coincided with the climate of Barkol. Accordingly, the wood remains of *Salix* and *Populus* contained special environmental information and an indication of effect.

As regards identified *Picea*, it is considered a timber of the outer coffin for tomb construction. Throughout history, *Picea* has been the best choice for construction purposes in Xinjiang due to its straight trunk. It is used as a construction material not only in Adunqiaolu site (Wenquan; 1870-1574 BC)[35], Yanghai Cemetery (Turpan; 1260 BC-AD 200)[15], and Shichengzi site (Qitai; 40 BC-AD 230)[43], but also in modern times. Nowadays, more than 95% of the timber in Xinjiang is made of *Picea schrenkiana*[29]. Moreover, wood of *Picea* was chosen as arrow shafts and fire-making tools[17,18] based on its characteristics of free-cutting[29].

Be different from *Salix* and *Populus*, which range from desert plains to high mountains, *Picea* only belongs to alpine forest vegetation, and *Picea*

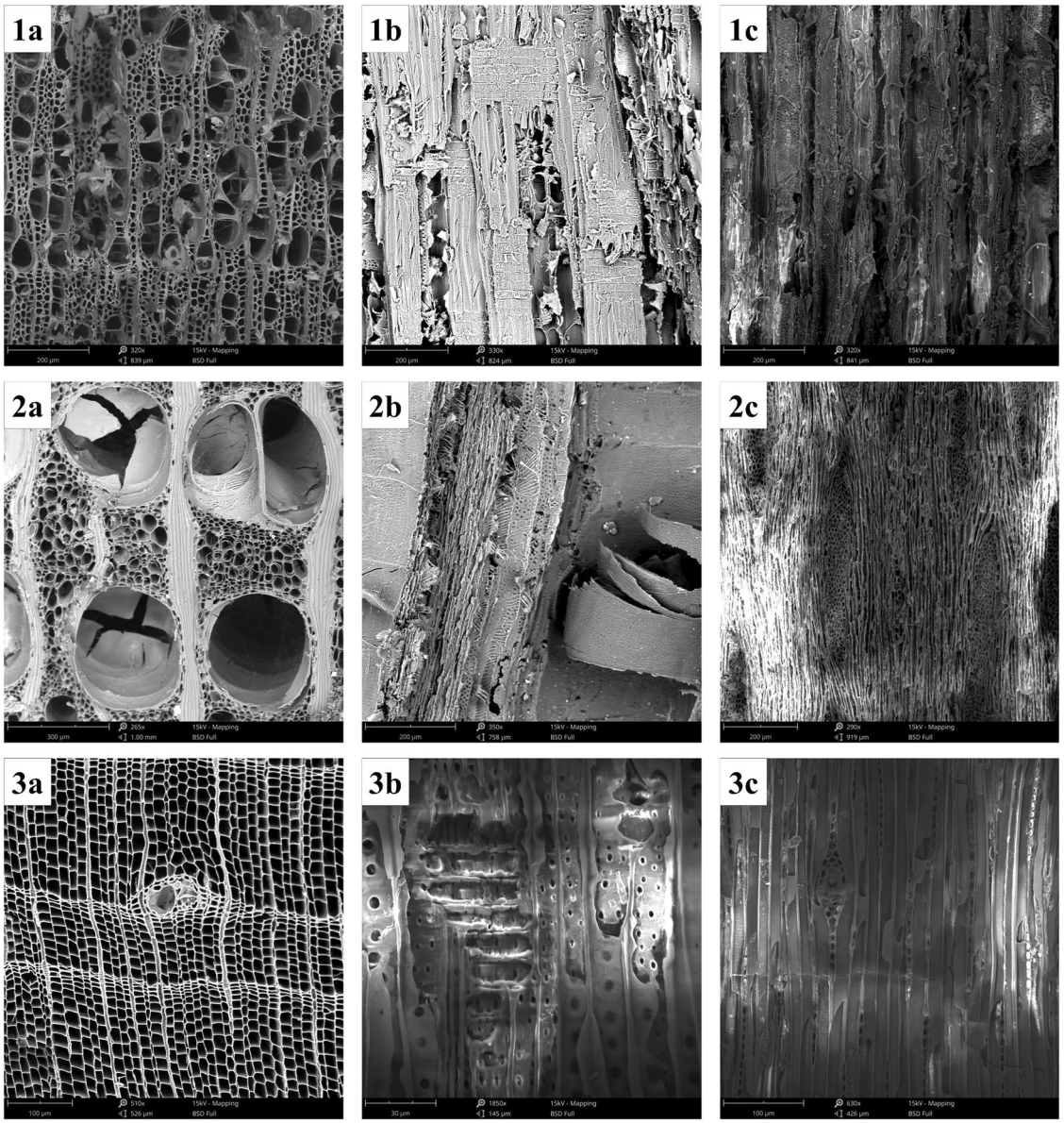

Fig. 5 | Microscopic anatomical characteristics of wood samples. 1, **2**, **3** respectively represent *Populus* sp., *Ulmus* sp., and *Picea* sp.; **a**, **b**, and **c** respectively represent transverse section, radial section, and tangential section.

schrenkiana is currently the only species in the genus *Picea* of the Tianshan Mountains. According to the field investigation, it is distributed mainly on the north slope of the Tianshan Mountains with altitudes of 1500-2600 m, and on the south slope with altitudes of 2300-3000 m. Moreover, there is a little forest of *Picea schrenkiana* along the valleys at altitudes of 1400-1500 m on the north slope and 2100-2200 m on the south slope[20]. Furthermore, the total pollen concentration and *Picea* pollen concentration of Aydingkol Lake were all at high values during 150 BC-AD 790[44]. To sum up, wood of *Picea* was easily accessible at that time during hunting or transhumance.

There is just one species in the genus *Ulmus*, that is, *Ulmus pumila*[45], which grows in piedmont alluvial fans and oases of Xinjiang, and this species is identified in the wooden body of the lacquered wooden plate. The sap of lacquer trees, whose drying film-forming process in the air is within 2 hours[46], is absolutely necessary in the production of lacquerware. As a consequence, lacquerware is produced in regions where lacquered trees grow. According to the *Historical Records* (史记, 91 BC), there is no distribution of *Toxicodendron vernicifluum* and *Toxicodendron succedaneum*, which are the two species primarily used as raw material[47], in Xinjiang. During the Qin and Han Dynasties (221 BC-AD 220), they were mainly distributed in the Yellow River basin, the north of the Yangtze River, and the Qinling Mountain area. Based on the records of *Tang Liu Dian* (唐六典, AD 739), *Old Book of Tang* (旧唐书, AD 945), and *New Book of Tang* (新唐书, AD 1060), since the Tang Dynasty (AD 618-907), their distribution exhibited a trend of southwestward expansion, without extending into Xinjiang. It suggests that the lacquered wooden plate in this paper was from the Central Plains of China.

The wooden articles after the lacquering process have good performance in anti-corrosion and water resistance, which is why they can be preserved for thousands of years. To ensure the lacquer can better attach to the surface of the wooden body, the tree species with strong stability and crack resistance are the proper choices. Among them, *Pteroceltis tartarinowii* identified from a lacquer artifact of the M3 of Han Tombs at Mawangdui (Changsha, Hunan; ~168 BC) belongs to the same family as *Ulmus*[48], because the family Ulmaceae has advantages above and gleams after being painted[29]. As regards the lacquer-eared cup with wooden body of *Ulmus* excavated from No.1 Shuangdun Tomb (Lu'an, Anhui; ~83 BC), it indicates *Ulmus* is suitable for making wooden-bodied lacquerware[49].

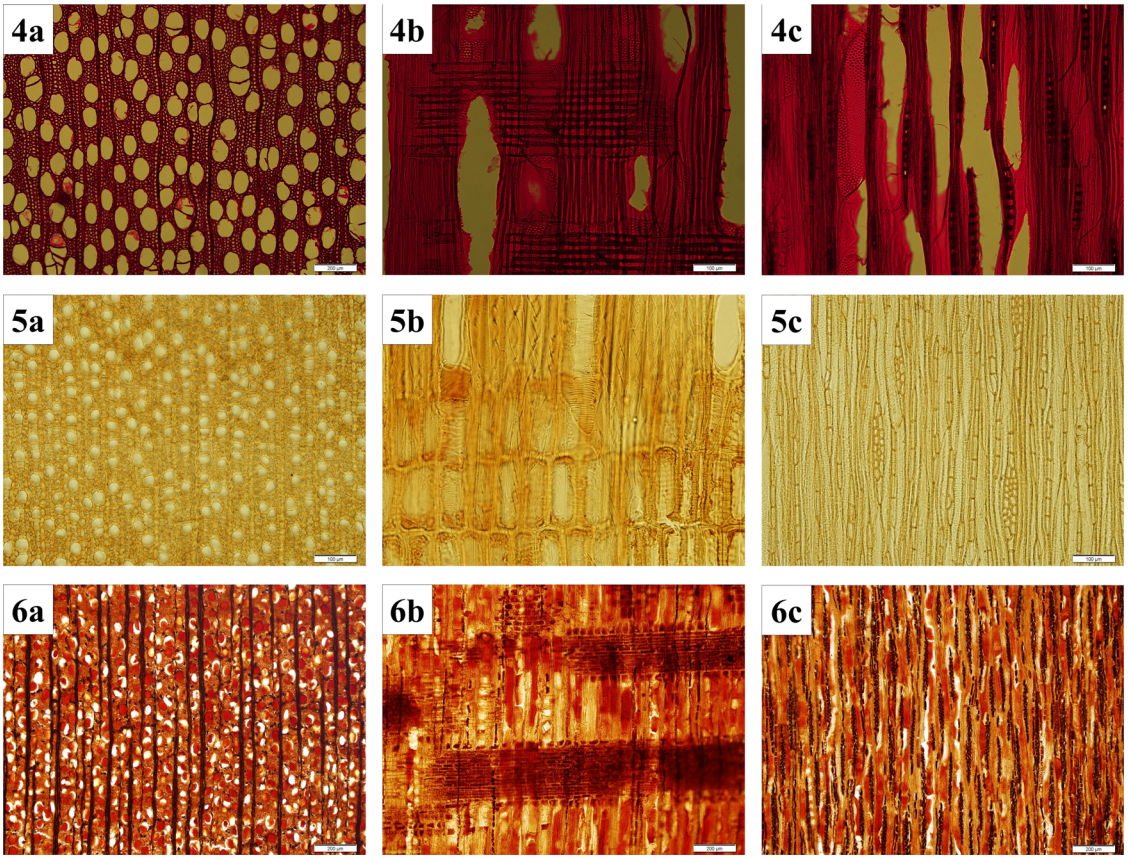

Fig. 6 | Microscopic anatomical characteristics of wood samples. 4, **5**, **6** respectively represent *Salix* sp., *Symplocos* sp., and *Photinia* sp.; **a**, **b**, and **c** respectively represent transverse section, radial section, and tangential section.

Moreover, *Ulmus* is famous for its high strength, toughness, and wear resistance. In this case, it was used as carriages (mostly shafts), shed wood, and weapons (part of crossbows) in the Terracotta Army Pit 1 at the Mausoleum of the First Emperor of Qin (Xi'an, Shaanxi; 247-208 BC)[50]. Square-columns of Qinglian Temple (Jincheng, Shanxi; first built in AD 550-559)[51], shafts of the carriages of Han Tombs at Dayun Mountains (Xuyi, Jiangsu; ~128 BC)[52], coffins of Han Tombs at Luobo Bay (Guigang, Guangxi; 203-111 BC)[53] and Chu Tombs at Jiuliandun (Zaoyang, Hubei; 334-221 BC)[54], and stakes of ancient bridges of Shahe (the second bridge; Xianyang, Shaanxi; AD 618–649)[55] and Jueshui (Xi'an, Shaanxi; 202 BC-AD 220)[56] also used wood of *Ulmus*.

In addition, combs of *Symplocos* and *Photinia* were also from the Central Plains of China, because *Symplocos* is distributed in tropical and subtropical regions of Asia[57], and *Photinia* is distributed in East and South Asia[58]. According to the material selection principles, hard, heavy wood with compact in structure and smooth fracture surface is suitable for making wooden combs[29]. It is surely no coincidence that both of *Symplocos* and *Photinia* have the same characteristics above. Because the ancestors of the Yushan site (Ningbo, Zhejiang; 4925-1250 BC) had long recognized the superiority of *Symplocos* and thus used wooden awls of *Symplocos* to drill holes as far back as 4925-3205 BC[59].

According to the Supplement to the *Compendium of Materia Medica* (本草纲目拾遗, AD 1765), woods of *Photinia* and *Buxus* were the two best materials for making wood combs. Combing the hair, especially with combs of *Photinia*, can stimulate the flow of blood and alleviate the uncomfortable symptom. During the Wei, Jin, Southern and Northern Dynasties (AD 220-589), combs gradually showed a decorative addition to the functional characteristics[60]. Consequently, combs were not only necessaries, but also ornaments. Considering that either men or women had long hair, and combs were private necessities. So, it implied that the combs made of non-local wood were brought or traded from the Central Plains to Turpan.

Wood utilization strategy

Besides excavated wood remains, the discovered Turpan documents also fully testify to the historical fact that ancestors cannot live without trees. As an important source of raw materials of the basic necessities, wood and its by-products covered almost every aspect of daily life, especially shelter and food. The mentioned tree species in documents[61] including timber trees like *Salix*, *Populus*, *Morus*, *Ulmus*, *Tamarix*, fruit trees like *Ziziphus jujuba*, *Pyrus*, *Amygdalus persica*, *Prunus armeniaca*, and *Vitis vinifera* etc. Actually, there was already a clear classification of tree species between timber and economic forests. Although the stems of these economic trees were undiscovered, their existence was proved by the excavated fruit or seed remains and pollen records[62–64].

Earth building was the main structure type in ancient Turpan, but it has some connatural shortages, such as low material strength and bad structural integrity[65]. As a result, long pieces of wood, called *renmu* (桩木), were inserted horizontally into walls during the construction of the city. They were equivalent to the current steel bars in the concrete. And the irregularly shaped small circular holes on the surface of walls of the ancient city of Gaochang were traces left by these timbers[21]. When wood becomes the main structural component of houses, the thickness of the wall and weight of the roof can be effectively reduced. It is worth noting that the wood of *Morus* was used as rafters according to the ancient discovered Turpan documents[61]. In these cases, wood of *Salix*, *Populus*, *Picea*, and *Morus* should be the main natural resources selected for construction in ancient Turpan.

Woodworks also held a prominent position among daily-use items. For instance, bowls, plates, small cups, chopsticks, combs, rulers, and staffs made of wood were recorded in Turpan documents[61] and unearthed from archaeological sites. As for transport tools, there were some references to bullock-carts made of wood in documents[61]. Furthermore, a painted wooden bullock-cart unearthed from Astana Cemetery reinforced the authenticity of these documents. Meanwhile, the records of the types of military

equipment were relatively rich, including *leimu* (檑木, wooden beams swinging from the city wall to attack the enemy below), crossbows, bows, and arrows[61]. Moreover, wood has been used for centuries for fires, whether for heating, cooking or even rituals. Though there were very few results about excavated charcoal remains, especially the identification of tree species, in Turpan. The discovered documents offered proofs that the wood of *Tamarix* was used as fuelwood[66].

As for timber forests, they were planted extensively in gardens or along the ditches for greening and shade, so that some places of Gaochang were called "*Salix* Valley", "*Tamarix* Spring", "*Ziziphus* Ditch", and "*Ulmus* Ditch" in historical records[61,67]. At that time, the worship of Buddhism became important in many households with Buddhism went deep into daily life[68]. Because of the same period of time with Gaochang Ruins and the discovery of abundant wooden structural components, the construction of hundreds of Buddhist temples and caves might be the cause for the mass production of timbers[69,70]. It is noteworthy that the utilization of wood from the Tianshan Mountains was relatively later, most likely due to the growing scarcity of local wood resources. All in all, wood utilization in Gaochang was comprehensively displayed from multiple points of view according to the discovered woodware and documents.

Cultural integration

Serving the deceased as if they were alive was a common practice in ancient times. The funerary objects hidden in the dark space underground reproduced the afterlife and the life of their owners. In the present study, determinable occupants of tombs included Zhang clan from Dunhuang (Gansu) or Nanyang (Henan), Qu clan from Jincheng (now known as Lanzhou, Gansu), Kui clan from Tianshui (Gansu), and Kang clan from ancient Kang State (Samarkand, Uzbekistan)[4,71]. According to the previous studies, the Kang clan (Sogdians), as the prominent merchants along the Silk Road[72], had already expanded trade to the Central Plains as early as the Spring and Autumn Period (770-476 BC)[73]. Especially during the first century and a half of the reign of the Tang dynasty (AD 618-907) of China, a period of heightened Silk Road activity, Gaochang was a centre of commercial and cultural interchange between Sogdian and Chinese[74]. Therefore, these clans were inevitably influenced by the culture of the Central Plains.

The hand-held, as a symbol of wealth, placed the hope of being rich after death. It actually dated back to at least the Neolithic period because of the hand-held bone spears excavated in the Dawenkou site (Tai'an, Shandong; 4150-2650 BC)[75], and became a common funerary during the Tang Dynasty (AD 618-907). Thereafter, it was widely discovered in the Central Plains region[76]. The hand-held also served as an important part of the funeral customs in Gaochang. Differing from traditional types of hand-held jade or coins, hand-held wood was more popular here. A large number of hand-held woods unearthed in Gaochang were the concessions made on material selection limited by the local environment, as well as the insistence on burial customs passed down from generations.

The burial wooden figurines also originated under the concepts of the immortal soul and postmortal enjoyment. They came out of the ancient Chinese system of human sacrifice (the living is buried with the dead), emerged in the Western Zhou Dynasty (1046-771 BC), and were especially popular in the Chu State (11th centery-223 BC)[77]. Replacing human sacrifice with wooden figurines, as a manifestation of social progress, was generally accepted and gradually derived animal figurines[78,79]. The custom of burying wooden figurines arrived in Xinjiang with immigrants from the Central Plains and became prevalent in Gaochang. The local artisans even integrated regional culture and created new varieties of figurines, like camel figurines[80]. A large number of well-preserved human and animal wooden figurines excavated in Gaochang mainly benefited from an arid climate[81,82].

Among these wooden animal figurines, the number of wooden duck figurines is the highest[80]. Their original form came from the pottery duck figurines found in burial objects from the Warring States period (475-221 BC) to the Tang Dynasty (AD 618-907) in mainland China. These painted wooden duck figurines had an extremely similar appearance to painted pottery duck figurines excavated from tombs of the Han and Tang Dynasties in the Central Plains. In Gaochang, their owners included both Han Chinese and ethnic minorities, reflecting a cultural fusion phenomenon between different ethnic groups. The identification confirmed that one of the wooden duck figurines was made of wood of *Salix*[83]. As a hygrophilous arbour, trees of *Salix* mainly grow alongside the rivers or lakes[29]. These results indicated that wetland animals and plants were widely distributed in the surrounding areas at that time. Furthermore, the mural paintings discovered in the tombs of Gaochang, which depict duck-rearing scenes, suggested that rare and valuable wild ducks might have been either fed or hunted by the local residents, particularly the upper-class nobility[83].

The shape of wooden combs in this paper is horseshoe shape (Fig. 3g, j). Blending Western Regions elements, the horseshoe-shaped combs were the typical style of the Central Plains since the Han and Jin Dynasties (202 BC-AD 420)[84]. On account of archaeological excavation reports, combs of the Western Zhou Dynasty (1046-771 BC) and before were only discovered in the Central Plains[85]. Thereafter, the scope of application was spreading nationally, especially the most popular horseshoe-shaped combs. Moreover, the headwear style of *Futou* (幞头) and *Jinzi* (巾子) discovered in Astana Cemetery reflected the Central Plains cultural characteristics[86]. Wooden combs can also be used as headwear, so the abundance of excavated wooden combs in Xinjiang also intimated the cultural identity and emotional affiliation to the Central Plains culture.

It was worth noting that the lacquered wooden plate in the present study (Fig. 3d) used a kind of craft called *Mujiazhu* (木夹纻), namely sticking linen on the wooden body before painting it. This craft, matured in the middle and late Warring States Period (334-221 BC), can not only repair wood defects to achieve firmness and stability, but also avoid the exposure of wooden bodies to improve the appearance. The lacquerware made using this craft was unearthed in No.172 Yangzishan Tomb (Chengdu, Sichuan; 475-221 BC)[87], Haojiaping Tombs (Qingchuan, Sichuan; 475-221 BC)[88], ancient wells of Huaibei (Huaibei, Anhui; AD 25-220)[89], and even Lelang Tombs (Pyongyang, North Korea; AD 25-220)[90]. In the 18th century, this craft was still used in Japan[91]. These wooden-body lacquerware was the important witness of cultural diffusion.

Wood and its processed products, which carried origin information, served as significant manifestations of cultural exchange and communication. As well as wooden combs of *Symplocos* or *Photinia* and a lacquered wooden plate of *Ulmus*, textiles unearthed in Xinjiang were also considered important material evidence of the spread and exchange of cultures in ancient Eurasia. The used dyes are not only local, but also many exotic dyes from the Central Plains of China, and even from Middle East and Western Asia[92–95]. The movement of material culture, people, things, and ideas beyond their places of origin involved many layers of cross-cultural interaction[96]. These culturally alien elements affected the native societies of early medieval Gaochang, and made Gaochang such a hearth of multiculture in China.

Discussion

There are 6 tree species identified from 11 wood samples, including *Salix* sp. (36.36%), *Populus* sp. (27.27%), *Ulmus* sp. (9.09%), *Symplocos* sp. (9.09%), *Photinia* sp. (9.09%), and *Picea* sp. (9.09%). Based on the distribution of tree species and previous research, it is indicated that wood of *Salix*, *Populus*, and *Picea* was selected in the locality. However, the lacquered wooden plate made of *Ulmus*, combs of *Symplocos* and *Photinia* were from the Central Plains of China. *Salix*, *Populus*, and *Picea* were common tree species in Xinjiang, so wooden objects and timber from them were excavated widely from cemeteries or sites. The wood of *Populus* and *Salix* is very suitable for handcrafting because of its characteristics of low hardness, fine texture, and well-distributed, while *Picea* is the best choice for construction purposes due to its straight trunk. Because *Ulmus* has the advantage of strong stability, crack resistance and gleams after being painted, it is chosen as the wooden body of lacquerware. The hard and heavy wood of *Symplocos* and *Photinia* has the characteristics of dense in structure and smooth fracture surface, so it is suitable for making wooden combs. It shows that the wood utilization of ancestors was based on wood characteristics, and wood selection was limited by local vegetation.

The discovered Turpan documents provided a much broader view of wood utilization. The mentioned tree species include *Salix*, *Populus*, *Morus*, *Ulmus*, *Tamarix*, *Ziziphus jujuba*, *Pyrus*, *Amygdalus persica*, *Prunus armeniaca*, and *Vitis vinifera*. They provided construction timber, fruits and fuelwood, as well as vital raw material in making woodworks, transport tools, and military equipment. Through the Silk Road, the funerary tradition in the mainland spread to Xinjiang. After integrating with local culture, the funeral customs in Xinjiang formed their own unique style. The material of hand-held excavated here was different from other areas, because ancestors selected wood to make hand-held. In addition, the local artisans created new varieties of figurines, like camel figurines. And wooden duck figurines were most popular here. Moreover, horseshoe-shaped combs and *Mujiazhu* (木夹纟) craft were also tied to the Central Plains culture. What they commonly share is the remembrance of past years and adherence to the customs and traditions of their hometown.

Data availability

No datasets were generated or analysed during the current study.

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Competing interests

The authors declare no competing interests.

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