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WOOD IDENTIFICATION OF ANTIQUE TOOLS USED FOR MANUAL PAPER PRODUCTION

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Abstract:

This paper deals with the identification of the wood species used for the production of wooden tools in an ancient plant for manual paper production.

After a quick historic contextualisation of the importance of the paper industry developed in the Pescia district (Tuscany, Italy), this paper describes the process of manual paper production and the different tools, mostly wooden, used by the workers. The historic plant "Le Carte" still preserves these tools, which were sampled to scientifically identify the timber species. Samples were drawn from any wooden component of the equipment involved in the whole manual paper making process. Sampling was performed on any portion of the artefact where the species of origin was not clearly and reliably identifiable by eye, or aided by a manual magnifying lens.

In total, 1223 identifications were performed and 25 timber types observed. Most of timber identifications regard the large mould collection (434 artefacts, 1154 identifications, 17 timbers), while the equipment included fewer artefacts, identifications and timbers.

Obtained results are then technologically discussed, considering the features of each species and the specific needs of each final use.

Key words: *species identification; wood anatomy; manual paper; wooden tools*.

FOREWORDS AND AIMS

The manual paper production industry settled along the river Pescia and around the homonymous town (Northern Tuscany, Italy) from the XV century, strongly influencing both the town and surrounding countryside.

The importance of this industry is now exemplified by the establishment of "Documentation Centre of the history of paper working " which is also home of " Paper Museum Association NPO "in the building of the former primary school in town Pietrabuona. The old factory called "Le Carte" (built in the beginning of XVIII century, but active until the '90s of the XX century), purchased in June 2003 by the Association from the paper mill Magnani 2000 SpA (Bini 2012) is being converted into a museum.

The manual production of paper sheets needed several specialised workers, each characterised by a role and a skill with a specific name. Historical manual production of paper within the paper mill "Le Carte" in Pietrabuona di Pescia, used the following materials: water, as a driving force and solvent of the mixture for the production of paper sheets; macerated plant fibres and animal glue, as raw materials of the paper. The production tools were made of local stone (Pietrabuona means "good stone"), several different types of wood and cast-iron probably introduced during the nineteenth century.

Wood is involved in the tools that lead to the production of the finished sheet at every stage, with the exception of drying. The specific function of some of the tools is not completely clear, as is their assembly them, suggesting that a few decades can be enough to endanger a production process that shaped the local social community over several centuries. The re-discovery of traditional timber uses in the recent past, allows us to understand some aspects of the way of life of the past and the relation to natural environment (Melo Junior & Torres Boeger 2015).

The paper mill is nowadays under restoration, to become the site of the Museum of Paper. The building still preserves the entire original equipment for paper production, dated to XVIII - beginning of XIX century.

This equipment is: a battery of hammers, moulds, drying press and tools for sheets finishing. The watermarked mould collection is the largest one in the Museum (450 artefacts); including one mould dating to 1812 that shows the side faces of Napoleon and Marie-Louise to celebrate their wedding. Other objects, such as canvas, waxes, stamps and dies used for the production of watermarked sheets are also held within the collection. Most of the artefacts are made partially or totally of wood.

CNR-IVALSA was appointed to investigate the watermarked moulds, to identify the tree species, evaluate their state of preservation and study the methodology used to assemble the moulds. The work was preliminary to the official recording and registration within the Museum collection. Then the second step was the analysis of other wooden equipment used for manual paper production.

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The general aims for both the steps were:
- understand the knowledge of wood utilisation at the time;
- know which species may be used in the course of maintenance and repair of equipment, prior to their entry in the new collection of the Museum.

The Italian standard UNI 11161:2007 establishes the proper requirements that one must take into account in the conservation, maintenance and restoration of wooden artefacts that are a part of our cultural heritage. The standard defines the essential criteria that must be followed when carrying out interventions.

Among them, the work performed for and with the Museum followed the requisites related to wood technology: wood identification and diagnosis of the state of the artefact (and its single wooden components), through identification, classification and quantification of biotic and abiotic degradations.

The aim of the paper is the description of the identification of wood species and discussion of the possible selection of species determined by their final use. Wood identification was performed following a scientifically sound path: wood anatomy is the most efficient tool to identify historically used timbers, including pieces of arts (Lisboa 1994, Kristjansdottir et al. 2001, Giachi et al. 2003, Timar et al. 2012, Ruffinatto et al. 2014, Melo Junior and Torres Boeger 2015, Macchioni et al. 2015, Mileto et al. 2016).

MATERIALS AND METHODS

The analysed wooden samples come from the watermarked moulds and the equipment for manual paper production.

The Moulds

The moulds for paper sheet production are made of a rectangular frame on which the metal cover is stretched, frequently with a woven watermark, working as a filter for the deposition of the fibre felt (Fig. 2). Below the metal cover several small wooden laths, technically called ribs, act as braces to avoid the deformation of the frame (Fig. 1, right); they also have a specific shape to facilitate the dripping of water.

Fig. 1.
On the left a complete mould made of the frame stretching the watermark. Above it another loose frame, called "deckle", that shapes the paper sheet. On the right the lower part of the frame showing the small wooden laths called "ribs".

Another wooden rectangular frame, loose above the mould, completes the filtering system. It is called a "*deckle*" and gives the final shape and dimensions to the paper sheets. To speed up the paper production the vatman had a couple of moulds with a single deckle (Loeber 1982) to prepare a second sheet during the couching of the previous one, thus the collection has half the number of deckles compared to moulds.

During the diagnostic evaluation, several moulds showed traces of small joinery modifications that added new elements and different wood species to the original moulds.

The Equipment

The wooden samples were drawn from any wooden component of the equipment involved in the whole manual paper making process (Fig. 2): hammers, Hollander, vat edges, pulpit of the coucher, trolleys for first drying, press, benches for the final operations and turbine of the water mill power plant.

The Sampling

The drawing of a sample must be always considered damaging for the artefact. The Italian standard UNI 11118:2004 establishes that the sampling must always be under the permission and the direct observation of the curator of the artefact.

The authors always tried to reduce as much as possible the sampling and, as stated in the standard, they were made close to damaged areas and as hidden and small as possible to reduce the aesthetic impact on the artefacts.

Fig. 2.
Three examples of the wooden equipment: a double press on the left, the battery of hammers in the centre, the pulpit of the coucher on the left.

To define the specific composition of each artefact the sampling was made on any portion of the artefact whose timber species was not clearly and reliably identifiable by eye naked, or aided by a manual magnifying lens (up to 10x). Every different component was taken into account; including the small elements added for repairs.

When the macroscopic observation was not sufficiently reliable, a portable USB microscope allowed observation of specific anatomical features on cross sections, thus avoiding further sampling.

When the macro and aided observations didn't allow a reliable level of identification, a small sample was drawn. It was then put in a marked vial that was photographed on the sampling location.

Samples were then brought to the laboratory for anatomical observation, where they were cut along three anatomical directions (cross, longitudinal radial, longitudinal tangential) and observed under an optical microscope. Cuts were made by hand using a razor on a freezing plate (Fig. 3).

Fig. 3.
Hand cut of a sample by a razor. The sample is blocked on a freezing Peltier plate.

More in detail, samples are boiled until they get to the bottom. After boiling, the sample is finished preparing the surfaces corresponding to the three anatomical directions of wood, this operation is performed with the aid of a stereoscope.

The orientated sample are then put on the freezing side of Peltier plates in order to be cut for obtaining thin sections, using ice as a vice. The cut is made by hand, using industrial razor blades with rigid spine.

The thin sections obtained are finally placed on a glass slide with a few drops of glycerol and covered with a coverslip for observation under the optical microscope

To identify timbers, the observed features were compared to the descriptions in Jacquiot 1955, Schweingruber 1990, Nardi Berti & Edlmann Abbate 1992.

RESULTS AND DISCUSSION

In total, 1223 identifications were performed, and 25 timbers identified. Most of the identifications regard the large mould collection (434 artefacts, 1154 identifications, 17 timbers).

Table 1 shows the final summary of the identified timbers and their classifications according to the use within the production plant.

The following microscopic images in this paragraph were obtained during the identification of the samples. Thus, their quality is determined by the dimensions and quality of the samples and by the practical work on this kind of observation, aimed principally at identifying the timber.

Table 1

Identified timbers and their functions within the artefacts.

Timber	Artefact category	Artefact	Identifications
Silver fir (*Abies* sp. cfr. *alba*)	moulds; tools	frames; fixing components; ribs;	7
Spruce (*Picea* sp. cfr. *abies*)	moulds; equipment	fixing components; ribs; covering system of the Hollander machine	80
Boxwood (*Buxus sempervirens*)	moulds	fixing components	1
Chestnut (*Casatnea sativa*)	tools; equipment	structural components of press	4
Cypress (*Cupressus sempervirens*)	moulds; equipment	frames; fixing components; deckles; ribs; hammers components	734
Ebony (*Diospyros* sp.)	moulds	fixing components	1
Heather (*Erica* sp.)	moulds	wooden nails - pegs	3
Beech (*Fagus sylvatica*)	moulds	frames; deckles; fixing components; ribs	8
Ash (*Fraxinus* sp.)	tools	blocking system	1
Apple tree (*Malus* sp.)	moulds	deckles	1
Mahogany (*Swietenia* sp.)	moulds	frames; deckles	62
Walnut (*Juglans regia*)	moulds; equipment; benches	ribs; structural elements of press; press screws	24
Obeche (*Triplochyton scleroxylon*)	moulds	fixing components of frames	1
Elm (*Ulmus* sp.)	equipment	vat edges	1
Alder (*Alnus* sp.)	tools	shears	1
Pear tree (*Pyrus* sp.)	moulds	ribs	1
Stone pine (*Pinus pinea*)	moulds	deckles	1
Pitch pine (*Pinus* sp.)	moulds	fixing components	3
Scots pine (*Pinus sylvestris*)	moulds	frames; fixing components; ribs.	195
white pine (*Pinus* sp.)	moulds	ribs.	48
Poplar (*Populus* sp.)	moulds; equipment; benches	fixing components; press rotating wheels; benches	12
Oak (*Quercus* sp.)	equipment; tools; benches;	press structural elements;	29
Black locust (*Robinia pseudoacacia*)	equipment; tools	hammers; palette for Hollander	3
Willow (*Salix* sp.)	benches	bench drawer	1
Service tree (*Sorbus* sp.)	equipment	turbine wooden teeth	1
Total			**1223**

The raw materials selected for the manual production of paper were rags of cotton, hemp, linen and special dyes. Rags, after being cleaned, underwent a specific mechanical and chemical maceration and a reduction to the fibre grade through stacks of multiple beating hydraulic hammers.

The beating battery system that beats down the rags into pulp, was made of robust, local hardwoods: black locust and deciduous oak (*Quercus* sp., pertaining to the *Quercus* subgenus, Fig. 4); some small secondary components, mud flaps, were made of cypress wood. Selected species had to be not only hard, but also heavy to apply a powerful load, beating the rags prior to maceration. Normally, in wood strength and density co-occur. Even if *Robinia* (black locust) cannot be strictly considered a member of the Tuscan flora, nevertheless is perfectly adapted to the local climate from some centuries, thus we can now call it a local hardwood (Gellini and Grossoni 1997).

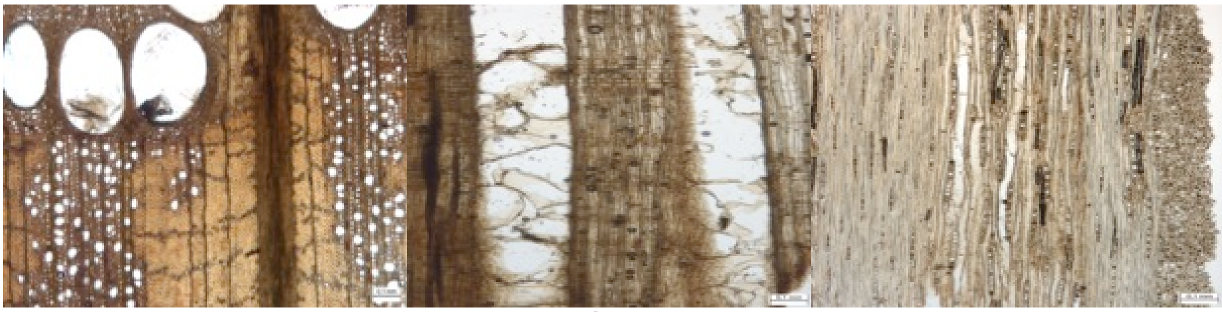

Fig. 4.
Quercus sp. a) cross section (ref. bar 0,1mm); b) radial section (ref. bar 0,1mm); c) tangential section (ref. bar 0,1mm).

Fibres were then refined by the so-called Hollander machine. The Hollander at the Museum is a stone oval basin, local made, on which the metal gears of refining system are installed. The part made of wood is the covering of the cylinder and blades of the machine. This is one of the most modern machines of the plant, thus the wooden components are just small spruce boards, likely not produced in the inner joinery of the plant. The palette used to shuffle the pulp is clearly a homemade tool made out of black locust timber.

The refined homogenised pulp, ready to become paper, was then moved to the stone vat, where it was warmed and mixed with the right amount of animal glue (gelatine). To ease the work of the vat worker, the edges of the stone vats were made out of elm and ash wood, directly fixed to the stone. A wooden pulpit, made of oak wood, further protected the work of the *coucher*.

The mixture was collected by means of special tools, the moulds already described, to produce the paper sheets. The *vatman* plunged the mould in the vat and pulled out the same amount of pulp that was then distributed over the entire surface of the metal cover: the paper sheet was obtained through a process of union between the vegetable fibres to form a uniform surface.

Felting of the fibres was obtained by means of the metal covers; they are composed of a set of small bronze wires disposed at right angles and spaced by a few millimetres between them, held in place by the chains. Vegetal fibres felt on this surface by allowing the water to drain through the wires. The metal cover is mounted on a rectangular wooden frame (the mould). The work surface is delimited by a frame of wood, called "deckle", that is not fixed but rests on the perimeter of the metal cover to allow the sealing of the pulp and thus delimiting the size of the paper sheet that will be obtained.

Once the sheet had formed, the *vatman* passed the mould to the *coucher*. After leaving the sheet for a moment to allow the water to drain, the *coucher* reclined the mould on a wool felt, separating the sheet from the mould. This operation, reduced the water content by one half, and allowed the sheets to detach from the paper felts. According to the average productivity of a manual paper plant, the cycle of dipping and couching to produce one sheet of paper takes under 25 seconds (Loeber 1982).

Most of the work of the inner joinery was probably devoted to the production and fixing of the moulds. Some of them were clearly heavily used, because they exhibit signs of friction where they were held, marks that now seem sort of handles. Generally speaking, there are two groups of moulds: the first one is of local production, made of local species (cypress and pines), while a second, smaller group is of British production, certified by a copper brand label, made of mahogany and pine.

Cypress wood is light coloured, even the heartwood, which is resistant against insects and very durable to fungi (Giordano 1997). This feature is crucial, because the typical environment of use, very humid and warm, made the moulds prone to xylophagous but also to warping and distortion. To face this problem only clear, quarter sawn wood was used, without a single defect; moreover, the joinery had precise prescription about the treatment of cypress timber before its transformation into boards and artefacts: stems were maintained for many years, before being sawn, in the water stream of the canals giving power to the

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plant. Probably this long “hygro-treatment” helped in releasing the growth stresses and reducing warping when subsequently used. The corner connections of the frame elements are then tightened by vertical wooden pegs made with small branches of heather.

The British moulds were made out of a tropical timber, the mahogany (*Swietenia* sp., Fig. 5) from Central America. During XIX century, British traders had a monopoly on wood trading from the Caribbean, and mahogany was the most important commercial timber from the region, specifically from Honduras (Bowett 2012).

Mahogany wood is also durable against fungi and resistant to insects (Tsoumis 1991) and the radial cut of the wood prevents warping. From the point of view of present times, it seems odd to find such a precious wood to produce an industrial tool, but at that time the availability of mahogany was still large and the price affordable. Nowadays the *Swietenia* species from Central America are protected by the Washington convention.

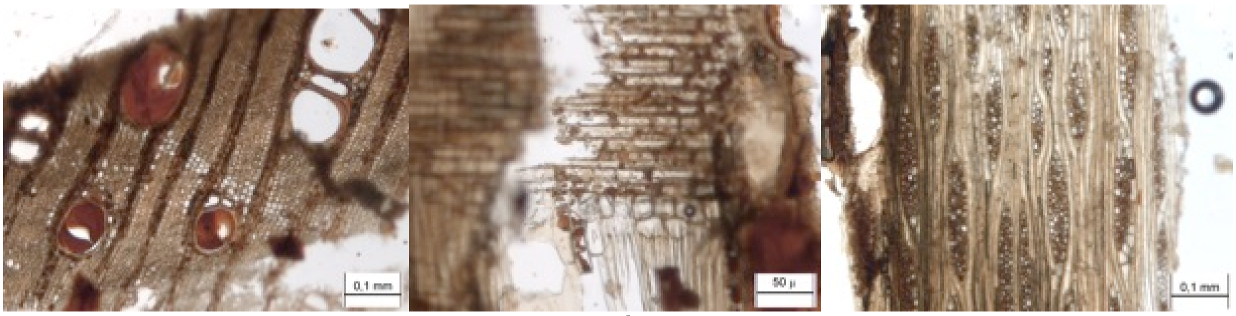

Fig. 5.
Swietenia sp. a) cross section (ref. bar 0,1mm); b) radial section (ref. bar 50 μm); c) tangential section (ref. bar 0,1mm).

Also, the small laths called “ribs” require accurate selection of the material to have elements that do not warp, ensure good mechanical performance and lightness. All the ribs are made of softwoods, the local ones were made out of local timber, like cypress, but also of timber derived from the wood trade at a national level, such as Scots/Austrian pine and spruce from the Alps. The last two woods are susceptible to insect attack and a few of those elements show severe attacks from both long horn and furniture beetles. All the British moulds possess ribs made of White pine (*Pinus* sp.), a North American softwood.

Wood species for the whole mould production must have another important technological feature: they had not to release coloured extracts when used in warm water, to not stain the fibres and the paper mat. All the listed timbers are light in colour, with the exception of mahogany, which is deep red. Nevertheless, the extractive content of the *Swietenia* species is low (around 3,5% Fengel & Wegener 1984); moreover, we could also expect a pre-treatment of wood used for mould production through a hot water washing, described by Loeber (1982).

The fibre mats drained out, shaped and dimensioned by moulds and deckles, were then laid down (couched) on damp cloths piles, as felt blankets, stacked on wooden trolleys, that were not plane, but bent to drain down the water dropping from both paper sheets and cloths. The trolleys were made out of well selected oak wood to not rot in a wet environment. The stacks made of alternate layers of felt blankets and paper sheets were then gently pressed in manual wooden presses to increase, through pressure and drying, the transformation of the fibre mat into paper sheets.

The following phases of sheets production was then performed by three different specialised workers to separate paper from the felts: the *poster* that removed the upper felt to dispose it in the stack of felts that the *coucher* will then use in the new round of production of sheets from the vat. Then the *breeder*, who detached the sheet from the lower felt, helped by the *container*, and placed the sheet on the pile of moist sheets called *post* which was subjected to a second mechanical pressing.

The three big presses (one of them is double, Fig. 2 left) that have been sampled have a constant composition, probably showing a common production. The struts are made of oak or chestnut wood, the big upper crosspiece is always made out of 2-3 elements of walnut wood (Fig. 6), as are the screws and the rotating system. The lower, mobile, crosspiece, the one directly pressing on the stack, is made of oak wood. Some secondary parts of the system that allow rotation of the screw can be also made of poplar. The wooden levers used to apply the rotating movement to the screw are always made of chestnut.

Finally, the sheets were individually exposed to natural ventilation by hanging them over hemp ropes in a drying room, normally an attic with numerous large windows. This was the only production step in which no wooden tool was involved in: the drying of the sheets pulled out from the stacks was made by a simply hanging the sheets in the air, normally in the attic of the plant, the so called “drying loft”.

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Dried sheets have rough edges (the so-called “deckle edged sheets”) that need to be cut to achieve commercial dimensions and shapes. All the final operations before selling were made with several benches and tools, frequently made out of different metals, mostly cast-iron, and wood. In most cases the timbers were poplar, willow and oak, but for some specific tools also alder, chestnut and walnut were used.

Fig. 6.
Juglans regia a) cross section (ref. bar 0,1mm); b) radial section (ref. bar 50µm); c) tangential section (ref. bar 0,1mm).

During the XX century, a power plant was installed to produce electricity from the water that already provided power to the beating system of hammers through a camshaft. Large oak beams support the big cast-iron turbine (Fig. 7). To reduce the roar of the cast-iron gears, the teeth of the horizontal turbine are made of wood and they chose service tree wood (*Sorbus* sp. probably *domestica*) due to its hardness and ability to stand the friction.

Fig. 7.
The turbine producing electricity: the teeth of the upper gear are made of service tree wood.

CONCLUSIONS

The 1223 identifications allowed 25 species or group of species to be found, among them 5 softwoods and 4 hardwoods were considered to be most abundant. 11 timbers were found only once, thus they must be considered very specific (like *Sorbus* for gear teeth) or sporadic, of almost accidental use.

The choice of the timber, apparently local, was always well related to their final use; a technological explanation for the timber choice was always clearly evident.

The most important aspect was high durability, due to the typical working environment characterised by high humidity and temperatures, making timber prone to fungi and insect attack.

Indeed, the small sapwood portions show decay caused by *Anobidae* attacks.

Local moulds were always principally made of cypress wood, with a high selection of the material, without any defects and quarter sawn to achieve dimensional stability. Imported, British moulds were always made of mahogany wood, selected with the same accuracy.

Bibliographic sources confirm the importance of the mahogany trade by the English, starting from the beginning of XIX century, principally from Honduras. Mahogany is a hardwood with a fine straight grain, that is highly humidity resistant and does not warp if well-seasoned. The British have used this material for over a hundred and fifty years, producing moulds soundly constructed and easy to handle.

All moulds should not release dying substances when plunged in warm water, to not affect the colour of the paper. Cypress does not release coloured extracts, while mahogany underwent a long treatment in hot water before being worked to become a mould.

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