Can laser cutting be an alternative technique for marquetry completion in furniture conservation?

Elena Jover Casanovas
FURNITURE CONSERVATION

Carl Malmsten - Furniture Studies
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ABSTRACT

This study describes experiments and findings of an investigation to evaluate the use of laser cutting as an alternative to traditional sawing techniques in marquetry completion conservation. Experiments on veneer from 11 different species of wood, covering ring porous, semi-diffuse/-ring porous and diffuse porous woods, were carried out and examined. The optimal cutting metrics with respect to speed, power and frequency for the types of wood were determined.

The most important ethical question for a conservator is to be able to preserve as much as original material as possible. The results of this project show that the use of a laser cutting machine is indeed a suitable solution to produce replacement veneer for marquetry works in furniture conservation with respect to quality and time. Especially when it comes to the precision in the shape of the replacement piece, laser cutting is superior to hand sawing. This makes laser cutting an interesting option and reduces the need for expert skills in hand sawing in order to perform very detailed completion work. It also reduces the need of invasive work on the original marquetry to accommodate the replacement piece.

The findings are general for all of the examined types of wood. On the negative side, the laser cutting machine requires a relatively big initial investment, making it difficult to say if it is really a cost-effective method of cutting replacement veneer pieces.
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I have always been very curious about new materials and new technologies and how they can be used in furniture conservation and, as a conservator, I have not restricted my interests to only traditional materials and techniques. I have recently attended to the 12th Conference on the Conservation of Contemporary Art, a 2-day seminar (20 hours) organized by the Museum Reina Sofía in Madrid and the Spanish Group of the International Institute of Conservation, GEIIC (Madrid, 17-18 February 2011), where I got to learn about new materials and alternative processes in conservation which was very interesting and enriching.

I have earlier worked with marquetry conservation and I always found problematic the way to fit a new piece of veneer into the marquetry work without removing some of the original material that surrounds it. That is the reason why, as soon as I had the chance to work with a laser cutting machine, I decided that it was worth trying to cut veneer to complete an old marquetry work.

Since I have a background as a graphic designer I think is appropriate to take advantage of it and use it and combine it into the world of conservation and, like this, get new and interesting results as well as alternative.

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1. INTRODUCTION

One of the most common damages in old marquetry objects is the ungluing and the consecutive loss of veneer pieces. The need of completion and retouching is big but also causes concern: What is ethical and when does a conservation activity becomes a reconstruction? And technically and economically: how is it possible to get the right material for the complementary veneer pieces? And how reasonable is it to spend huge costs and time for a completion of a furniture object whose value in the furniture market might be low?

It is very important to preserve as much original and old material as possible when conserving and restoring an object: it is an ethical question. With the laser cutting machine it might be possible to do a minimum of invasive work, but not with the traditional hand-sawn methods since the veneer is quite sensitive. In order to complete the missing parts, remaining parts are often adjusted to the new ones and not the other way around, as it should be done. But since the veneers break easily and sawing by hand cannot be as precise as we would like, especially when sawing small pieces or very detailed ones, it is difficult to get a good result without removing part of the original material.

Fig. 1: Example of how original material has been removed to adapt to the new veneer
1.1. Aim of the project

The aim of this project is to experiment with a laser cutting machine in order to produce the missing veneer pieces from old marquetry objects and furniture without removing any original material. This method should be suitable, cost-effective, sustainable and reversible compared to traditional hand-sawn methods.

1.2. Questions/Issues

○ Can a laser cutting machine replace the traditional method of hand-sawn inlays in the conservation work while maintaining the quality standards?
○ Which of the processes is more time- and cost-effective for a conservator?
○ Which wood is best suited for laser cutting?
○ Which are the advantages and disadvantages for the use of a laser cutting machine compared to traditional methods?

1.3. Delimitations

What I am going to investigate in this report is if it is possible to substitute the traditional methods of hand-sawing marquetry with a laser cutting machine.

It is not my intention to make a deeper determination of the veneer specimens with microscope analysis but only to look into the (simple) physical properties of the selected veneers. That is to see if there are any difference between woods of different species, like if a more fibrous veneer would be cut differently than a compact one. All the specimen veneers are knife sliced veneer and not sawn or turned veneer.

At the same time, it is not important for my experiment to look into a specific marquetry sawing technique, but rather to check the results with any hand-sawing technique.

The project will not cover possible conservation and restoration of the case-study piece, since I do not pretend to write a conservation report but an investigation report instead. So, questions like the causes why the pieces of veneer are missing or why they broke in a certain way, will not be answered.
1.4. Method

From a case study of a Dutch table from the end of the 19th century, four different complementary pieces will be produced by hand using the traditional sawing marquetry methods and then produce exactly the same pieces using a laser cutting machine. The results will be compared, traditional vs laser cutter, with regard to time, cost and aesthetic expression, for eleven different types of wood.
2. BACKGROUND: VENEER AND MARQUETRY PRODUCTION THEN AND NOW

2.1. Marquetry and its origins

Marquetry is the name given to decorative patterns made of wood inlay, composed of wood veneers from different species. The wood pieces differ with respect to grain, color and texture, which are used to produce a variety of effects when used both in complementary and contrasting manners.\(^1\)

Marquetry and inlay were inspired by the ancient craft of intarsia: the making of decorative and pictorial mosaics by the inlaying of precious and exotic material into or onto a groundwork of solid wood. Intarsio is the Italian term used for the inlay technique on the 15\(^{th}\) century.\(^2\)

Marquetry arose in Egypt in the 14\(^{th}\) century B.C., when skilled craftsmen decorated low tables and coffers with colored woods, precious stones, glazed tiles, gold and ivory (e.g. in the Tutankhamun's grave). Through the centuries, craftsmen were employed by rich patrons to create marquetry works. But the process was both expensive and scrupulously because it involved many steps, from the import of woods, carving, lowering and ditching a groundwork to sawing and slicing the hardwood, fitting and setting the pieces with glue or mastic, to end scraping, grate down, waxing and burnishing the inlay surface.\(^3\)

Later, this technique came to Europe, where over the course of the years, it was perfected. It was in the 14\(^{th}\) century when marquetry was produced in the way we know today, when schools of marquetry were set up in Italy to promote the practice, using chisels to shape thick pieces of veneer and since then it spread fast around Europe.\(^4\) During this time, the motives where mainly architectural, formal and geometric. Later, in 1562, the jig saw was invented, which made it possible to produce more complicated designs. Until this time, the marquetry pieces had been cut or sawed piece by piece and around 1620 a new technique was invented. This new technique consisted of placing different veneer pieces on each other, making a packet, and then sawn through them in a straight angle, which left space between the pieces. Later, Charles Boulle (1642-1732) developed this technique and introduced the possibility of using new material like metal and turtle shield.\(^5\)

During the 18\(^{th}\) century, specially in Europe, marquetry reached its peak with the completion of amazingly intricate designs. This was thanks to the use of a new type of saw called marquetry

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1 The historical information in this survey is based upon following sources, if nothing else is indicated:  
2 Brunne (1996)  
3 Shapland (1926)  
4 Burman (2008)  
5 Gilbert (1999)
donkey saw, which allowed to saw many pieces of veneer at the same time. This became the starting point of mass-produced marquetry. At the end of 18th century a new way of sawing arose that allowed to saw in angle, which improved the results by getting the pieces very tight with each other.

Marquetry is still used in modern furniture production as well as in furniture conservation.

2.2. Veneer production

There are three ways of veneer production:

2.2.1. Sawn veneer

Before the turning machine was invented in the 18th century, all the veneers were produced by sawing. These veneers were around 3 mm thick.

2.2.2. Turned veneer

This method includes wetting the log, fixing it through its ends and turning it against a big and sharped knife. This is an effective method to get big slices of veneer. Turned veneer gives clear patterns thanks to the tangentially cut through the growth rings. The veneers can be sliced to a minimum of 0,5 mm of thickness.

2.2.3. Knife sliced veneer

With this method is possible to obtain decorative veneer from hardwood. The log is first cut longitudinally and then the growth rings are studied in order to estimate how veneer will be cut to get the most interesting and valuable grain. Then the log is cut in halves or quarters which are mounted in a flexible holder. When the log is pressed against the knife, slices of veneer are cut. The thickness of the veneers produced by this method is minimum 0,5 mm.

![Fig. 2: Veneer production: sawn (left), turned (center) and sliced veneer (right)](image-url)

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6 Worth 2001) and Cronborg (1965)
Nowadays veneer is only produced by sawing if they are hard to produce by turning or when it is hard to get a certain pattern. It is common that furniture conservators produce homemade veneers by sawing. The veneers used for the experiment are all knife sliced with a thickness between 0.5 to 1 mm.

2.3. Marquetry in the traditional way under the 17th century

2.3.1. Piece-by-piece technique

This is the most used marquetry technique which allows to produce many copies (up 20) of the same marquetry motive at the same time. The first step is to make a package with layers of veneers and then to glue the traced model on paper on the top veneer. Each piece is sawn separately with a donkey saw, which saws in straight angle. This process requires high accuracy and that is why it is important that the model is traced with a line not thicker than 0.2 mm. After that, the sawn pieces are picked up and placed on a flat surface, reconstructing the model and finally gluing them on the surface. If some space is left between the veneer pieces it is possible to fill this space with a mix of dust and glue.\(^7\)

2.3.2. Multilayer technique

This technique means that one entire marquetry motive is cut at the same time with a keyhole saw which has a adjustable basis. The motive traced on paper is also glued on the top veneer, drawn with a thin line. The veneers are packed depending how they are placed on the drawing, differentiating the background from the rest. The veneers are sawn in angle (5-8° depending on how many layers) in layers of four to five veneers so that the resulting pieces fit perfectly into and next to each other. This technique is suitable for motives with a lot of details that demand a high accuracy but when the wood texture is not so important.

2.3.3. Carbon technique

This technique is a simplification of the multilayer technique where the structure and fiber direction of the wood is important for the motive. This technique is done with the motive backwards, which is drawn on a transparent paper for after turn it and trace it to the veneer. The background has to be the same size as the whole motive and the sawing has to start always with the background and up. Once the first piece (background) is sawn, the next piece in order up to the top is sawn as well and taped to the background. While sawing the pieces, they are taped to each other. At the end the motive is glued on a support and sanded, then the motive will appear on the surface. For this technique a keyhole saw is used.

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\(^7\) Burman (2008)
2.4. New ways of producing marquetry and marquetry completions

Laser cut marquetry is already in use since several years but mainly in the production of standardized marquetry designs for furniture decoration. With the help of a computer-aided drawing program (CAD\textsuperscript{8}-program, like Adobe\textregistered Illustrator\textregistered and AutoCAD\textregistered) and the accuracy of the laser cutter it is possible to produce exact images as the ones that are seen on the computer screen.

There has been some attempts to find a suitable way of cutting completion veneers because, as described above, the results with traditional hand-sawn methods cannot be always precise and detailed.

One of these attempts is the proposal of Mats Frii, a former student from Carl Malmsten - Furniture Studies, who suggests to complete the missing veneer with a photo, with the following procedure: photograph the damaged area and with the help of Adobe\textregistered Photoshop\textregistered and the clone tool, reconstruct the missing piece. After that the new “piece of veneer” is printed on photo paper and the surface is treated as the surface of the object (i.e. wax or shellac). Finally it is glued to the damaged area. This way it is possible to get the exact shape of the area to be completed and to choose the right fiber direction and color. However, except from the fact that the new piece it is not real veneer, it might be problematic due to the fast color degradation of the photos (i.e. by sunlight), which is why this proposal might be rejected.

On the other hand, there are some companies\textsuperscript{9} that have specialized in producing faux bois paper, i.e. fake tree paper, achieving very good results and getting a real marquetry feeling when seen. Each piece is cut and pasted by hand. With this material, which allows for a more economical and ecological production, it is possible to produce marquetry for big surfaces. The disadvantage of this approach is that the sense of touch disappears when touching the surface, since it is only paper. Another problem is that the paper can be easily damaged when in contact with water or scratched.

On the next page are some examples.

\begin{footnotesize}
\begin{itemize}
\item[CAD: Computer Aided Design]
\item[http://www.thenewmarquetry.com]
\end{itemize}
\end{footnotesize}
Another former student from Carl Malmsten - Furniture Studies, Victor Thelin, presented his thesis in 2010 about *Laser cut marquetry: a complement to older marquetry techniques*\(^\text{10}\), where he looked into the possibility of substituting the “piece-by-piece” marquetry sawing technique with laser cutting in production of new furniture. He reached the conclusion that it was a good alternative for the traditional methods but that its use would reduce the feeling of real handicraft provoked by using a traditional hand-saw.
3. REALISATION/PERFORMANCE – A CASE-STUDY

3.1. The current object

Even though I could have made my study without any actual object, I chose to perform my experiments using an existing table as a starting point to make my research as authentical and relevant as possible. The table in question is a Dutch table from the end of 19th century with flowered marquetry. The object is not of the highest quality, which is one of the reasons why it has this precarious state of conservation. This can also be seen when observing the areas where veneer is missing, where newspaper is seen through, telling us that the veneer was first glued on newspaper and then glued to the blind tree, a sign of pre-industrial production.

The table is 113,8 x 84,5 x 71 cm and built in baroque style from the end of 19th century. It has typical baroque turning legs which ends with bun feet and are stabilized with a star base. The table has only one drawer on the frontal part with two round handles. Marquetry covers all the surfaces of the table: board, drawer, sides, cross and even the blocks of the legs. The coating is a very thin layer of shellac, which in some areas is missing.
The marquetry has different thicknesses, from 0.3 to 1 mm, and this difference of thicknesses might be due to earlier restorations, when the marquetry has been sanded. The veneers composing the marquetry are rosewood (*Dalbergia nigra*), which in most of the table sides has lost its darkness because of the sunlight exposure, and boxwood (*Boxus sempervirens*), which has become quite yellow for the same reason. Only on the front part has preserved its original color thanks to almost no exposure to sunlight.

The motive of the marquetry is floral. On the board center there is a flower vase with flowers, which stands on a board. Not everything is floral though, there are also some birds and line edging with some scroll ornaments along them. The composition is not symmetrical so different flowers and their placements are different all over the table. As well as flowers, birds, edging and ornaments are made with boxwood veneer, and for the background only rosewood is used. The pieces are placed in a way that intends to create a perspective sensation, with pieces cut in regular shapes, like squares and triangles, and placed with the fibers in different directions to gain this perspective sensation. The light veneers has dark edges made with sand shading, a pattern-technique in which veneers are toned to create shaded, three-dimensional effects. This is made through heating clean, fine, silver sand and dipping the veneers for about five to six seconds until the required degree of toning has been achieved (this process is also called sand-scorching).\(^{11}\)

The object is a loan from Jean Cedstrand, that kindly has let me work with it.

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3.2. The approach /Procedure

3.2.1. Selection of materials

I started the experiment process by determining the different sorts of wood used in the Dutch table by visual inspection - rosewood and boxwood. These two woods are very interesting and different from each other, not only because their different colors and fiber textures, which create great contrast, but its provenance and its properties.

Since the aim of the experiment was to test the different cutting effects in several woods other than those used on the table in question, I chose a number of woods which have different and interesting properties. It was not possible to find boxwood veneer so similar veneers have been chosen as a substitute. All woods chosen are commonly occurring in marquetry work from 17th to 19th century. I did not it consider necessary to identify the specific specimen of all the samples with microscopic analysis, since the aim of my experiment was to see the way the laser cutting machine cuts on veneers.

The chosen woods were divided into three groups, depending on its pores: ring-porous, semi-ring/-diffuse-porous and diffuse-porous. The size, number and distribution of vessels and fibers determine the appearance and uniformity of hardness of a particular wood. To determine which kind of wood belongs to a certain pore group, the wood should be analyzed, preferably with a microscope.

To be able to understand how the pores are distributed, a brief explanation of the tree growth is necessary. Cell formation in most trees follows a cycle, which includes a growing season and a dormant season, resulting in visible growth rings. Those rings vary depending on the species, climate and more or less favorable conditions during the growing season. Growth rings can be very obvious while others can be nearly invisible. The differences of a growth ring in a particular species will be determined by seasonal variation in cell diameter and cell-wall thickness and the distribution of the different kinds of cells within the wood. When there is a visible contrast between the first-formed and the later-formed growth rings, the first-formed part of a single growth ring is called earlywood while the later-formed parts is called latewood.

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Fig. 6: Classification of pore transition from earlywood to latwood

A. Ring-porous woods
The woods in this group have radially arranged latewood pores, like in oak, but they can also be found arranged in wavy bands, like in elm. The most difficult to identify are the ones with pores extended from solitary or small radial multiples to a bundle, like ash.

A.1. Oak (*Quercus robur*)
A light tanned to biscuit colored, usually straight grain (irregular or cross-grained material can be found as well). It has distinct earlywood with up to four pores in width and the transition from earlywood to latewood was abrupt. The wood is extremely resistant and hard. Not as easy to glue as other woods but takes waxing, liming, fuming and polishing treatments very well.

A.2. Elm (*Ulmus procera*)
A brown-green veneer with a mild, stripy figure, even growth and quite straight grain. This ring-porous wood has its largest pores usually in a single row, giving a coarse texture to the wood. The wood has good bending properties. Gluing is good and polishes or waxes to a high finish.
A.3. Ash *(Fraxinus excelsior)*
A cream-colored veneer with a dark, wavy grain. Its texture is coarse but even and has a tough, flexible and straight grain. A ring-porous wood with two to four pores wide, surrounded by lighter-colored tissue. The wood is heavy, tough and dense and it is fairly split resistant. Stains easily and can be brought to a smooth and excellent finish.

![Fig. 9: Ash veneer](image)

B. Semi-ring-porous or semi-diffuse-porous woods
As its name suggests, these woods have neither a ring-porous nor diffuse-porous distribution. The pores are perceptible larger in earlywood than in latewood and only a few woods strictly show this type of pore distribution, like walnut.

B.1. Cherry *(Prunus avium)*
A reddish veneer with straight grain and a fairly fine and even texture. Its pores are small, uniformly distributed and solitary and in multiples and small bundles. The wood has a medium bending and crushing strength. Glues and stains well and can be brought to an excellent finish.

B.2. Walnut *(Juglans regia)*
A grey-brown veneer with infiltrations of darker color irregularly distributed. Its grain is straight to wavy with a coarse texture. Its earlywood pores are fairly large, decreasing gradually to quite small in latewood. The wood has high crushing strength and medium bending strength. Gluing is satisfactory and the material polishes to a high finish.
C. Diffuse-porous woods
The woods in this group have remarkably large and fairly numerous rays that are easily visible on any surface and its pore size and distribution is considerably uniform through most of the ring.

C.1. Beech (*Fagus sylvatica*)
A cream-white veneer with a delicately flecked figure: has a straight grain and fine, even texture. Its pores are small and evenly distributed through earlywood. The wood offers medium resistance and a high crushing strength. Glues easily, stains well and takes an excellent finish.
C.2. Plane (*Platanus acerifolia*)
A light reddish-brown veneer with very conspicuous and numerous broad rays present on quartered material. The wood has a medium strength and low stiffness. It glues well and stains and polishes to an excellent finish.

C.3. Silver Birch (*Betula pendula*)
A creamy brown veneer with a wavy water-marked figure: it has a straight grain and fine textured and lustrous. Small to medium pores size, distributed solitary or in radial multiples of two to several. The wood has high bending and crushing strength. Glues well and can be stained and polish to a good finish.

C.4. Pear (*Pyrus communis*)
A pinkish-brown veneer with very fine rays and pores, straight grain and a very fine and even texture. The wood is fairly tough and very stable. It glues well and is specially good for staining and polishing to a high finish.

C.5. Rosewood (*Dalbergia nigra*)
A chocolate-brown to lighter purplish or reddish brown veneer with darker contrasting streaks. It has an undulating grain, a coarse texture and is very fibrous. Its pores have variable size (small to large) unevenly distributed, solitary and in radial multiples. It has a high bending and crushing strength. Glues satisfactory and requires grain filling for an excellent polished or waxed filling.
C.6. Mahogany (*Swietenia mahogani*)

A light to reddish-brown veneer with straight, interlocked or irregular grain, moderately coarse textured to medium. Its pores are solitary or in radial multiples of two to ten and evenly distributed. The wood has not good bending properties and provokes severe buckling or fibre rupture. Gluing properties are good and it may be stained and polished to an excellent finish.
3.2.2. Selection of the areas of work

After carefully observing the table, I chose four different areas with missing veneer, which have different shapes. I named the four areas 1, 2, 3 and 4 making it easier to follow my further descriptions.

1. an area in which a big part of the leaves are missing and one has to guess how they are placed
2. an area where the piece has been torn
3. an area with many tiny details
4. an area where the two types of wood are used

Fig. 18: Area of work 1
Fig. 19: Area of work 2

Fig. 20: Area of work 3
Fig. 21: Area of work 4
3.2.3. Methods

A. Hand sawing

A.1. Equipment

- Over head film
- Permanent marker 0,5 mm
- Carbon paper
- Donkey saw / Fret saw
- Sawing blade, number 1 mm
- Paraffin wax
- Veneers

A.2. Process and results

Marquetry can be hand-sawn in many ways, using a fret saw, a *donkey saw*, a scroll saw or simply using chisels or a sharp knife. Since the pieces that I was experimenting with were a completion of an existing design, I decided to use a mix between the multilayer and the piece-by-piece technique, taking advantage of their best strengths. This means the possibility of sawing the complete design at once with the multilayer technique, and the possibility to cut many veneers of different woods at the same time with the piece-by-piece technique. In an
ordinary completion situation, only one piece of a particular type of wood is needed. But since I wanted to compare the results between laser cutting and manual work for many different types of wood, I used the packaging of several different veneers to save time.

I decided to use the *donkey saw* to cut some of the veneers in the first part of my experiment, since that probably had been the tool used to cut the original veneers in the Dutch table. Another reason for deciding to use the *donkey saw* is that it was practical since it is possible to saw many veneers of different wood at the same time using a straight angle, which was important for my experiment to be able to compare it to the time spent when working with the laser cutting machine.

With overhead film and a permanent marker the outline of the missing veneer areas were traced and then carbon paper was used to transfer the outline of the drawing onto a paper. After forming a packet of five different veneers, the paper with the traced outline was glued on the top of the package. Next, a tiny hole was drilled next to the outline to be able to put the saw blade through it. Then it was possible to start sawing. Paraffin can be rugged to the blade to make the sawing process smoother. In this way all pieces are cut.

For the remaining sheets of the veneers, I followed the same preparation process but changed the *donkey saw* for a fret saw. This turned out to be harder to cut with due to the greater freedom of movement.

Since my goal was to save the original material around the damaged areas, I tried to saw the pieces with as high precision in the details as possible. One of the biggest problems turned out to be that the smallest or sharpest parts broke with the simple movement of the blade. So I found it quite hard to cut the details. For this reason I changed from the *donkey saw* to the fret saw. Unfortunately, the fret saw demands even higher skills to operate, and the saw actually gave me worse results.

![Fig. 24: Hand-sawn walnut](image-url)
In a real marquetry completion situation the conservator is likely to modify the original marquetry to accommodate the newly cut piece, unless he or she is extremely skilled with the saw. The alternative would be to try to cut the piece once more, repeating the process until a perfect fitting pieces is achieved. This would be an extremely time consuming process that is not likely to be used by a real conservator.
B. Laser cutting

B.1. Equipment

- Camera: Canon Powershot G10 (14.7 megapixels, RAW-format images)
- Computer: MacBook 2010 and normal PC
- Adobe® Illustrator® CS4 for MAC
- Adobe® Photoshop® CS4 for MAC
- Laser cutting machine: EPILOG Laser Legend 36EXT
- Veneers

Taking Victor Thelin's thesis as a basis, where the laser cutting machine is described, I learned how the laser machine works and how the veneer needs to be placed on the cutting board. I used the same laser cutting machine as Victor, since it is the one available at Carl Malmsten-Furniture Studies where the experiments were carried out. In his report he explains how the veneer has to be “flat and straight”\(^\text{14}\) because otherwise the cutting effect will be uneven or not cut through the veneer at all. He also describes his “study of the laser’s line thickness”\(^\text{15}\) and how to adjust the laser's speed and power to get the best results. Thanks to his results I did not need to do all the tests again for my report.

In the EPILOG Laser Legend 36EXT, the speed is adjustable in 1% increments from 1 to 100%. The slower the speed, the deeper the cutting. The power is also adjustable in 1% increments\(^\text{16}\).

\(^{13}\) Laser: Light Amplification by Stimulated Emission of Radiation
\(^{14}\) Thelin (2010), p. 13
\(^{15}\) Thelin (2010) p. 15
\(^{16}\) http://www.epiloglaser.com/legend_techspecs.htm
At a given speed, a higher power will produce deeper cutting. It is also interesting to know that hard materials will be cut at low speed and high power while soft materials will be cut at a high speed and low power.

B.2. Process and results

After photographing the four chosen areas of work, with a ruler next to them to be able to know the exact size, the photos were loaded to Adobe® Photoshop® CS4, where the size of the photos was adjusted to the real size.

Then the areas were traced and drawn in 0.025 mm paths (i.e. the thinnest) in Adobe® Illustrator® CS4, which is one of the computer CAD17-programs that the laser cutting machine recognizes in order to cut and draw. Adobe® Photoshop® and Adobe® Illustrator® are 100% compatible with each other and it is very easy and practical to work with both of them at the same time. I named the four areas 1, 2, 3 and 4 making it easier to follow my further descriptions:

Fig. 29: Paths drawn with Adobe® Illustrator®
Then the printing options for the laser, like the cutting boards size (914 X 610 cm), the speed, power and frequency, were set directly in Adobe® Illustrator®. The speed, power and frequency had to be adjusted and fine tuned for each type of wood to ensure the best possible result.

The first attempt was to try the laser cutting machine on paper in order to see if the paths where correct in size and shape. Fortunately, they were perfect in both size and shape and they fit exactly in the missing veneer areas. The values used to cut the paper on the laser cutting machine can be observed on the following chart.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Speed (%)</th>
<th>Power (%)</th>
<th>Frequency (Hz)</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>80 gr</td>
<td>90</td>
<td>10</td>
<td>478</td>
<td>OK. Cuts through</td>
</tr>
</tbody>
</table>

The next step was to try with a piece of veneer. The chosen wood was rosewood, the main wood used in the composition. These first tests were decisive for me since they were not only the firsts tests of the wood but also the first tests carried out by me.

After placing the veneer on the laser cutting board and the adjusting the values, the first test was carried out. It turned out that the laser power was not strong enough, resulting in the laser beam not cutting through the veneer. After several attempts and after adjusting the size of the paths, the laser's power, speed and frequency, I got the perfect size and cut of the rosewood veneer. In this way the aim of this project was accomplished and the pieces fit exactly on their spots.
Fig. 31: Rosewood veneer in area of work 2

Fig. 32: Rosewood veneer in area of work 3

Fig. 33: Rosewood veneer in area of work 4

Fig. 34: Rosewood veneer in area of work 1
All the tests and its results with the rosewood veneer can be appreciated on the following chart:

<table>
<thead>
<tr>
<th>Test</th>
<th>Material</th>
<th>Thickness</th>
<th>Speed (%)</th>
<th>Power (%)</th>
<th>Frequency (Hz)</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>10</td>
<td>478</td>
<td>Just marks the path, does not cut.</td>
</tr>
<tr>
<td>2</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>75</td>
<td>20</td>
<td>478</td>
<td>Just marks the path, does not cut.</td>
</tr>
<tr>
<td>3</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>80</td>
<td>50</td>
<td>478</td>
<td>Cuts but the pieces are too big.</td>
</tr>
<tr>
<td>4</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>50</td>
<td>478</td>
<td>Path reduced to 99%: still too big.</td>
</tr>
<tr>
<td>5</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>85</td>
<td>50</td>
<td>478</td>
<td>Path reduced to 95%: size Ok for path 1.</td>
</tr>
<tr>
<td>6</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>85</td>
<td>50</td>
<td>500</td>
<td>Path 2 too big.</td>
</tr>
<tr>
<td>7</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>30</td>
<td>Auto</td>
<td>Reduction of paths 2,3,4 to 98%: better size but not cut.</td>
</tr>
<tr>
<td>8</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>15</td>
<td>Auto</td>
<td>Good cut.</td>
</tr>
<tr>
<td>9</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>18</td>
<td>Auto</td>
<td>Does not cut through.</td>
</tr>
<tr>
<td>10</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>90</td>
<td>20</td>
<td>Auto</td>
<td>Does not cut through.</td>
</tr>
<tr>
<td>11</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>95</td>
<td>20</td>
<td>Auto</td>
<td>Cuts through. Red. path to 97%: 2 OK. Paths 3 &amp; 4 too small.</td>
</tr>
<tr>
<td>12</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Path increase to 99%: OK 4, path 3 still too big.</td>
</tr>
<tr>
<td>13</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Path reduced to 98%: path 3 still too big.</td>
</tr>
<tr>
<td>14</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Path reduced to 96%: path 3 still too big.</td>
</tr>
<tr>
<td>15</td>
<td>Rosewood</td>
<td>0,5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Path reduced to 93%: path 3 OK.</td>
</tr>
</tbody>
</table>

Looking at this results, it is obvious that it was difficult to obtain the right size of the cut pieces, which was quite puzzling since they fit perfect when I used the paper. And it is even more strange that not all of the four pieces needed to be reduced the same percentage but they needed to be adjusted individually.

After observing the results obtained with rosewood, I started doing the tests with the rest of the selected veneers, and I could observe that the thinner the veneer, the higher the speed was needed in order to avoid the burning marks around the silhouettes, which is one of the problems with working with the laser cutting machine. This is especially apparent when working with light color woods.

Below are the settings for the best results of the tests with the selected veneers, observing all its properties and how they react after being cut with laser. The results varies slightly, depending exclusively on its thicknesses and the type of fibers of the veneer samples. There are not differences on the results depending on the veneer classification in ring-porous, semi-ring-/diffuse-porous and diffuse-porous woods. In general, the quality of the best results were satisfactory for all of the different woods.
Best test results for the ring-porous woods:

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Speed (%)</th>
<th>Power (%)</th>
<th>Frequency (Hz)</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak</td>
<td>0.8 mm</td>
<td>92</td>
<td>22</td>
<td>Auto</td>
<td>Good flat sample. Very fibrous: It breaks easily.</td>
</tr>
<tr>
<td>Elm</td>
<td>0.5 mm</td>
<td>92</td>
<td>40</td>
<td>Auto</td>
<td>Good flat sample. Very fibrous: It breaks easily.</td>
</tr>
<tr>
<td>Ash</td>
<td>0.5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Good flat sample. Very fibrous: It breaks easily.</td>
</tr>
</tbody>
</table>

Best test results for the semi-diffuse-porous wood:

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Speed (%)</th>
<th>Power (%)</th>
<th>Frequency (Hz)</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cherry</td>
<td>1 mm</td>
<td>92</td>
<td>35</td>
<td>Auto</td>
<td>Light undulation. Resistant wood.</td>
</tr>
<tr>
<td>Walnut</td>
<td>1 mm</td>
<td>92</td>
<td>60</td>
<td>Auto</td>
<td>Very flat. Resistant wood. Good results.</td>
</tr>
</tbody>
</table>

Best test results for the diffuse-porous woods:

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Speed (%)</th>
<th>Power (%)</th>
<th>Frequency (Hz)</th>
<th>Results &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beech</td>
<td>0.8 mm</td>
<td>92</td>
<td>25</td>
<td>Auto</td>
<td>Good flat sample. Does not break easily.</td>
</tr>
<tr>
<td>Plane</td>
<td>1 mm</td>
<td>92</td>
<td>60</td>
<td>Auto</td>
<td>Very compact &amp; hard wood. Resistant. Great results.</td>
</tr>
<tr>
<td>Silver Birch</td>
<td>0.8 mm</td>
<td>92</td>
<td>40</td>
<td>Auto</td>
<td>Light undulation. Very compact &amp; fine wood. Great results with all the details.</td>
</tr>
<tr>
<td>Pear</td>
<td>0.5 mm</td>
<td>92</td>
<td>22</td>
<td>Auto</td>
<td>Very compact &amp; fine wood. Breaks easily.</td>
</tr>
<tr>
<td>Rosewood</td>
<td>0.5 mm</td>
<td>92</td>
<td>20</td>
<td>Auto</td>
<td>Light undulated. Breaks easily. Good results.</td>
</tr>
<tr>
<td>Mahogany</td>
<td>0.8 mm</td>
<td>92</td>
<td>40</td>
<td>Auto</td>
<td>Very undulated, fibrous &amp; compact. Good results.</td>
</tr>
</tbody>
</table>

The values of speed, power and frequency had to be adjusted lightly for every type of veneer, specially when the veneer was thicker or thinner. In order to work faster, which was one of my objectives, I chose to work with an auto frequency value, being the laser cutter the one that automatically chose the value that worked better for the chosen speed and power.

Another observation after getting the results for all the veneers is that it took a while to reach the values for the “perfect cut”, but once those are sorted out, the work goes smoothly. The solution to this would be to make a collection of all the values for the different veneers and their different thicknesses. Consulting this collection of optimal values before starting the work would save lots of time.

The laser cutting machine has an air compressor attached which removes heat and combustible gases from the cutting surface by directing a constant stream of compressed air across the cutting surface. At the same time, air is sucked from the cutting board. In order to get the best
results, the veneer has to be as flat as possible. Otherwise the air that comes out can blow away the already cut pieces, which can land under the beam of the laser. That would ruin the finished pieces.

Another problem caused by the air expelled by the laser machine is that when small pieces are cut, there is a risk of them being sucked up and lost. So, for both problems, the following solution could be applied: to only cut the pieces that must be cut and the rest to use the engraving option in the laser cutting machine, that will only mark those pieces instead of cutting them.

3.3. Results

Here is a comparison of the time used for the production of the four areas of work with 11 different veneers.

<table>
<thead>
<tr>
<th></th>
<th>Hand-sawing</th>
<th>Laser cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>20 to 25 minutes</td>
<td>15 to 20 minutes</td>
</tr>
<tr>
<td>Sawing/Cutting process</td>
<td>15 to 20 minutes</td>
<td>5 to 15 seconds</td>
</tr>
<tr>
<td>Assembly</td>
<td>15 to 20 minutes</td>
<td>5 to 10 minutes</td>
</tr>
<tr>
<td>Total time</td>
<td>Up to 65 minutes</td>
<td>Up to 30 minutes</td>
</tr>
</tbody>
</table>

Observing the results, one can see that the laser cut process is more time-effective than the traditional hand-sawing methods.

The results will vary depending on how many pieces need to be produced, being the laser cut method more time- and cost-effective than the traditional methods when many pieces need to be produced. But even if only one completion piece needs to be produced, the laser cut method is still more suitable because its detail and precision results. And even if the preparation time is almost the same as the hand-sawing method, the laser cut process will be faster.
4. CONCLUDING DISCUSSION AND REFLECTION

4.1. Summary of tests results

The aim of this project was to answer the following set of questions:

○ Can a laser cutting machine replace the traditional method of hand-sawn inlays in the conservation work while maintaining the quality standards?
○ Which of the processes is more time- and cost-effective for a conservator?
○ Which wood is best suited for laser cutting?
○ Which are the advantages and disadvantages for the use of a laser cutting machine compared to traditional methods?

Before answering the main (first) question of whether laser cutting can replace traditional methods, it would be useful to start with stating the advantages and disadvantages with laser cutting compared to traditional methods.

Advantages:

○ In question of seconds, any veneer piece will be cut, making the process very time-effective. Naturally, this affect the cost-effectiveness of the procedure since the major cost of conservation work is labour cost.
○ The position and selection of the veneer fibers can be easily chosen by oneself, by placing the piece of veneer in the correct direction on the laser cutting board or by placing the path on the correct position on the computer screen.
○ The degree of precision in the shape of the pieces to be cut is very high compared to traditional techniques.
○ Even conservators with less handicraft skills can produce superior results in terms of quality and detail.
○ By producing highly detailed replacement pieces, the need for adjusting the original marquetry around the area of the missing piece to accommodate the new piece is reduced, which is highly desirable in conservation.
○ The process minimizes waste of new veneer material, since the laser can cut very close to each piece. In this way, the space between the cut pieces is usable.
Disadvantages:

- The cost of the laser cutting machine is determined by its operation properties (speed, engraving table size, and laser wattage) and range from $7,995 to $45,000, which is a quite big cost for a workshop. If you also calculate the cost of the personal computer (approximately $1,500) professional licenses for the Adobe products (approximately $2,500) and a decent digital camera (approximately $500), it is obvious that the initial cost of the equipment is high.
- By introducing more automated processing in the work of the conservator, one could argue that the furniture is no longer “hand crafted”. In the long run, this could lead to a lower skill level among conservators in the traditional techniques.
- Not all types of woods have the same optimal settings of speed and power, which can be problematic unless an initial investigation is carried out and an “optimal settings” schema is established.
- Some problems arise when cutting small pieces which can be blown away by the air compressor.
- Sometimes a thin darkish shadow caused by the heat of the laser beam can appear in the edges of the cutting line of pale veneers.
- By replacing a manual process with an automated process more energy will be used, both in production of the machine and while it is operating. This makes the laser cutting less sustainable from an energy consumption view.
- A laser cutter is an advanced piece of machinery, and it is not very likely that a conservator could solve problems that arise or perform maintenance by oneself. This makes the dependence on service technicians from the laser cutter company high and leaves the workshop vulnerable to disruptions.

After testing different woods, my results show that the laser cutting machine works perfectly fine with all of them. More tests should be done in order to state that laser cutting is a suitable technique for any kind of wood. So far the results looks promising.

I also wanted to develop a method that would be cost-effective, making it possible for a greater public to have their furniture restored/preserved by a professional. As stated above, the process is definitely time-effective for a conservator, reducing the labour cost of each processed piece. However, the initial investment in equipment is high. This means that in order to make the process cost-effective, a large amount of processing needs to be done, since the cost of the equipment can be split on many produced pieces. Therefore, the cost-effectiveness depends
completely on the amount of work that can be done, and in general one cannot answer the question of whether laser cutting is more cost-effective or not.

My intention was first and foremost to develop a method in order to save as much material as possible left from the original surface. My research proved that this was possible with the help from the laser technique.

To summarize the discussion, my tests have shown that veneer laser cutting is indeed a viable alternative method for producing replacement pieces of marquetry.

4.2. To proceed /in the spotlight

My experiment has lead to findings and results which have demonstrated that marquetry pieces cut with laser are a good alternative to the much more time demanding traditional methods.

The main advantage of the laser cutting machine is that it is possible to cut the required piece very quickly and with extremely high precision. This means that one can change the veneers and/or designs very easily without the usual problems, like that the veneer breaking. It is quite easy to make a complete series of pieces just by simply pressing a button. Yet another advantage is that the laser cutter will totally and accurately replicate the design so that it will cut several different pieces from a sheet of veneer without wasting of the veneer making it fit perfectly in the missing veneer area.

With regard to disadvantages, it is an expensive machine, making it unlikely to be used in many smaller work shops. In order to make financial sense, a work shop need to have substantial amount of marquetry work demand. One has to have some basic computer drawing skills and will need to understand vector design techniques.

One way to tackle this problem would be to develop a specialized workshop with a laser cutting machine, where the workers of several small workshops could come to consult the expert operator or order the cutting of their needed pieces.

In the future, it is likely that furniture conservators have to adapt to new technologies and materials. This will probably lead to better results like the ones obtained with my experiment about marquetry pieces cut with a laser cutting machine.
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6. REFERENCES AND BIBLIOGRAPHY

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A good place to read about marquetry terms:

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7. APPENDIX

7.1. Table’s original color

On the following picture it is appreciable the original veneer’s colors, jacaranda and boxwood, that in the rest of the object has been bleached by sunlight.

Fig. 35: Original colors of the Dutch table: rosewood and boxwood
7.2. Table’s conservation status

On the following photos it is possible to appreciate the bad condition of conservation of the Dutch table: dirt, loss and missing veneer.

Fig. 36: Missing veneer and dirt

Fig. 37: Missing veneer in many different ways
Fig. 38: Loss veneer on the board

Fig. 39: The veneer had been glued on newspaper
7.3. Problems with laser cutting machine

The following photos show how important is to use a flat veneer to cut with the laser cutting machine because otherwise the veneer gets to close to the laser ray and it gets burned.

Fig. 40: Burned veneer caused by an wavy veneer

Fig. 41: The details disappear when the veneer is not flat
7.4. Area of work 4: Different veneer tests

On the following pictures it is possible to observe how the veneers are combine in the are of work 4 to recreate how a real restoration of the missing veneer could have been done. The tested veneers are not in the original woods.

Fig. 42: Combined veneer test: Walnut and plane
Fig. 43: Combined veneer test: Beech and mahogany