Transilvania University of Brasov

THE INTERDISCIPLINARY DOCTORAL SCHOOL

Faculty: Furniture Design and Wood Engineering

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# Perspectives on the development in furniture of some traditional Romanian motifs of textile heritage from Țara Bârsei and its surroundings

## SUMMARY

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**CONTENT**

## INTRODUCTION

Throughout the world, people are turning to traditional values that may, however, be adapted to current trends. The same applies to the "drawings" made with a needle or an embroidery hoop by our grandmothers or mothers when we were children, which we didn't know at the time were called "traditional motifs," but now we understand that they need to be brought back into focus.

Collecting traditional motifs from textile heritage objects, digitizing them, and transferring them to tangible and modern products represents an additional method of perpetuation alongside conventional preservation. Together, they serve to pass down these motifs from generation to generation, enriched over time.

A continuous recycling of ideas or knowledge from the past, which means a blend of old and new ideas, namely tradition and innovation, can be materialized through the presence of symbols and motifs in furniture.

The structure of the thesis is as follows:

**Chapter 1**, titled "Current Status of Research on Valuing Traditional Motifs from Textile Heritage," represents a literature review of methods for valuing and preserving traditional motifs from textile heritage, with a focus on the use of digitization as an innovative tool for obtaining transferable patterns through current technologies.

**Chapter 2**, titled "Aim and Objectives of the Doctoral Thesis," presents the overall aim and specific objectives based on which the proposed thesis was addressed and resolved.

**Chapter 3**, titled "Digitizing Traditional Motifs from Textile Heritage in the Țara Bârsei and Surroundings," presents the results of a collection and theoretical research activity regarding traditional motifs from textile heritage in the Bârsa Land and its surroundings. It describes the method and software used for digitizing these motifs, as well as the characteristics of stitches and sewing methods. Additionally, a database containing 100 digitized patterns from various museum and private collections is presented, along with the symbolism attributed by ethnographers.

**Chapter 4**, titled "Experimental Research on the Possibilities of Transposing Traditional Motifs onto Furniture Surfaces through CNC Milling," focuses on experimental research regarding the possibility of transposing traditional motifs onto furniture surfaces through milling on computer numerical control (CNC) machines. Fundamental and applied research regarding the surface quality achieved through milling in relation to the wood fiber orientation is presented, along with applied research involving milling and coloring technology to enhance the ornamentation on wooden surfaces.

**Chapter 5**, titled "Experimental Research on the Possibilities of Transposing Traditional Motifs onto Furniture Surfaces through Laser Engraving," continues the experimental research from the previous chapter, utilizing laser engraving as a method of transposing traditional motifs onto wood surfaces. An experimental investigation based on the study of color differences obtained through laser engraving with varying laser beam power is conducted. The results obtained through stereo-microscopic examination are presented, and a comparison between the two ornamentation technologies (CNC milling and laser engraving) is made based on the aesthetic characteristics of the transposed patterns on wood surfaces.

**Chapter 6**, titled "General Conclusions. Original Contributions. Dissemination of Results. Future Research Directions," concludes the doctoral thesis by summarizing the results obtained from the conducted research and indicating practical utilization possibilities, as well as future research directions. Scientific publications resulting from the research are mentioned, including those in ISI Web of Knowledge indexed journals with impact factors greater than 1, international conference presentations, participation in events, and a collaborative project with NORD ARIN company from Preluca, Neamț County, which involved the ornamentation of a furniture set (RAM table and bench) through CNC milling and coloring, presented at the International Furniture Fair in Milan 2022.

# CHAPTER 1. THE CURRENT STAGE OF RESEARCH ON THE VALORIZATION OF TRADITIONAL MOTIFS FROM TEXTILE HERITAGE

## 1.1. Methods of Valorization and Conservation of Traditional Motifs from Textile Heritage

### *1.1.1. Textile Heritage*

Heritage represents the natural, historical, and cultural legacy of a country and comes in various types, as depicted in Fig. 1.1.

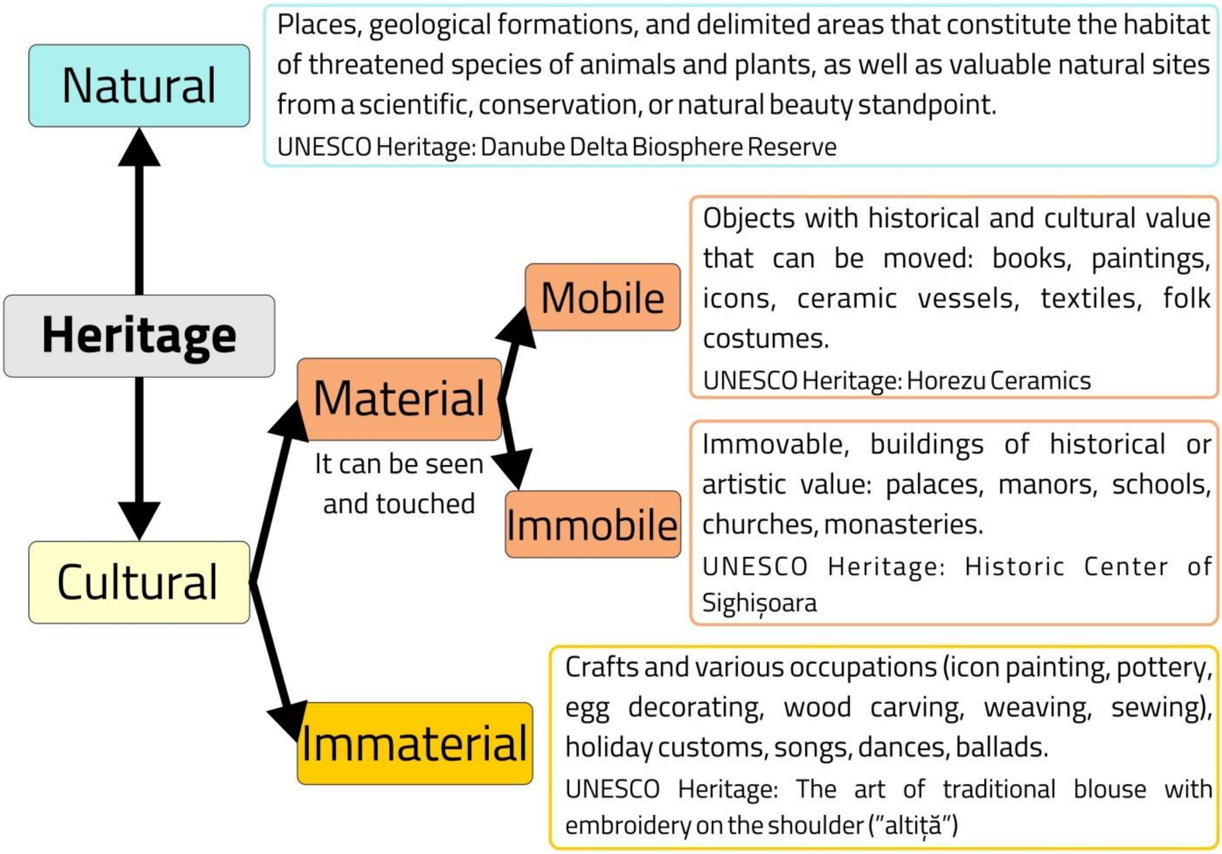



Fig. 1.1. Classification of heritage.

Textiles represent a special category of cultural heritage, expressing the power and diversity of fabrics. They offer a means of communication and expression through their meaning, scope, motifs, and textures. The transmission of knowledge and professional skills in this field is passed down from generation to generation, reflecting the aspiration for artistic perfection. Textile heritage encompasses a wide variety of aesthetically high-quality textiles that have endured over centuries (Muzeul de Etnografie Brașov, 2019).

### *1.1.2. Valorization-Conservation of Textile Heritage*

A study on the conservation of traditional textile collections in Romania highlighted the importance of the microclimatic factor in the degradation of textile materials, particularly due to the development of bacteria on their surfaces (Ilieș *et al.*, 2020). Non-destructive methods of investigation and treatment, such as radiation technology and nuclear techniques, have been developed for textile conservation (International Atomic Energy Agency, 2017). Not only are the motifs in textiles important, but also the natural dyes used for them (Petroviciu *et al.*, 2019).

Traditional textile artifacts are subject to copyright and industrial design protection (World Intellectual Property Organization, 2003). Folklore and cultural traditions need to adapt to current needs while maintaining a connection with ancestral traditions (Pozzo, 2020). The stories of Romanian women who weave and the use of traditional techniques and materials in textiles reveal changes in values and practices in this field (Buchcyzk, 2015a). For weavers, textile design represents a combination of technical choices, creativity, and experimental skills (Buchcyzk, 2015b).

Tradition and innovation in crafts can be interconnected, and diversifying traditional products can add aesthetic value (Naji, 2008), (Nugraha *et al.*, 2022). Analysis of textile design and structure, as well as the identification of signs of deterioration, can be facilitated by non-invasive imaging techniques (Serrano *et al.*, 2021).

Policies and practices for promoting and conserving craft heritage can be characterized by the use of technology and innovation (Yongzhong *et al.*, 2018). Heritage is considered a concept interconnected with community, nostalgia, tradition, and authenticity and is approached from a multidisciplinary perspective.

(The Faro Convention) promotes the understanding of cultural heritage and its relationship with the community and society (Fairclough, 2009). The United Nations Conference on Trade and Development (UNCTAD) has encouraged developing countries to improve their creative industries and creative economy, which intersect crafts, services, and the industrial sector. This represents a growing sector in global trade (United Nations, 2008).

## 1.2. Digitization, Digitalization, Digital Transformation - Innovative Tools Applicable in the Valorization of Traditional Motifs from Textile Heritage

### *1.2.1. Definitions*

Digitization involves transforming analog or non-digital information (present in physical format) into a digital format, such as scanning physical documents into digital files, converting typed text into a digital format, converting cassette audio into MP3 files, or converting film photographs into digital formats like .tiff or .jpeg (www.ditrama.eu).

Digitalization refers to the use of digital technologies and digital data to transform the way companies/institutions work and interact with customers, with the aim of creating new advantages through digital flows. An example would be automating manual processes by replacing manual form filling on paper with direct data entry into a web form or mobile application (www.ditrama.eu).

Gong and Ribiere (2021) define digital transformation as a fundamental change in an entity (such as an organization, a business network, an industry, or society) facilitated by digital technologies, aiming to bring innovation and radical improvements by strategically leveraging its key resources and capabilities to create value for stakeholders.

### *1.2.2. Software and Equipment Used*

The *Geographic Information System* (GIS) software was utilized for the digitization of 90 traditional motifs collected from folk costumes in the counties of Bihor, Arad, and Maramureș, yielding similar results to specialized graphic software such as *Inkscape*, *Adobe Illustrator*, or *Corel Draw*. A combination of the Radius-Vector (RV) functional method and Principal Component Analysis (PCA) was employed for comparison purposes (Ilieș *et al.*, 2020).

Traditional motifs from the ethnographic region of Transylvania were analyzed and stylized, preserving the characteristic symbolism and color of the area, using the vector graphics software *CorelDraw* (Doble *et al.*, 2017).

Other researchers (Wijnhoven and Moskvin, 2020) combined archaeology, the history of clothing, and digital technologies to replicate a ring armor using parameterization, computer-aided design (CAD), and rigid body simulation based on physical principles, demonstrating similarities between the original object dated from 150-220 AD and the obtained replica.

To assist designers in the process of incorporating traditional motifs as a source of inspiration, (Hou *et al.* 2023) proposed a method for representing the semantic characteristics of traditional motifs and developed a graphical user interface (GUI) program based on *MATLAB* software to construct a database of these motifs.

### *1.2.3. Research on the Use of Digital Tools in the Heritage Field*

Current digital technologies supported by graphic programs, computer-aided design (CAD), and computer-aided manufacturing (CAM) enable the replication of motifs found on old textiles and their transfer onto modern ones, thus contributing to their preservation (Doble *et al.*, 2017).

In the light of the Framework Convention on the Value of Cultural Heritage for Society (Faro Convention), a "new heritage" is emerging, which involves using the past in the present and renewing it for the future (Fairclough, 2012). Taking advantage of modern technologies, creative industries are capable of translating old traditional motifs onto new objects while preserving them in new forms (Sütçü and Karagöz, 2013).

## 1.3. Milling, Pyrography, and Painting - Opportunities for Showcasing Traditional Motifs from Textile Heritage in Furniture Ornamentation

### *1.3.1. Milling*

The methods of ornamentation used in the past have evolved along with new techniques and technologies for mass furniture production. One of these techniques is milling, which is performed using machine tools equipped with milling cutters, knives, or circular discs at high speeds and with feed movements (Hinescu, 1989).

Computer Numerical Control (CNC) machining centers in the furniture industry allow for milling decorations on the surface of wood. This is done by importing a vector file created using graphic software, which contains the design of the original motif, or by converting 2D digital images into 3D representations using specialized applications such as *Visual C++* software (Sood *et al.*, 2018).

The CNC carving process is based on optimizing milling parameters, selecting the appropriate tool, and processing method. To evaluate the quality of milled surfaces, studies have been conducted that measure roughness parameters (Pinkowski *et al.*, 2012), (Hazır and Koc, 2019), (Sütcü and Karagöz, 2012), (Supadarattanawong and Rodkwan, 2006), use mathematical models to adjust feed speed based on surface quality and cutting direction (Gawronski, 2013), or apply genetic algorithms in CAM software (Krimpenis *et al.*, 2014).

Assessing surface quality is extremely important both in the finishing process and in achieving a quality final product. Roughness parameters represent the main quantitative indicators of wood surface quality and can be measured using direct contact or non-contact roughness measuring devices, such as laser or optical roughness meters (Koc *et al.*, 2017), (Sedlecký *et al.*, 2018), (Starikov *et al.*, 2020), (Gürgen *et al.*, 2022).

Numerous studies have been conducted to evaluate tool wear and its impact on the processing of different wood species or wood-based materials (Ohuchi and Murase, 2006), (Aguilera *et al.*, 2016), (Pinkowski *et al.*, 2009), (Keturakis and Lisauskas, 2010), (Porankiewicz, 2006), (Aknouche *et al.*, 2009).

(Pinkowski *et al.*, 2009) found that roughness parameters Ra and Rz, measured after successive CNC milling of pine wood, decreased to values lower than the initial ones after tool wear.

Table 1.1 summarizes the research results included in the specialized literature.

Table 1.1. Results from scientific literature regarding milling

| Author | Wood species | Technological parameters | | | Roughness parameters | | Tool |
|---|---|---|---|---|---|---|---|
| | | Feed speed, m/min | Milling depth, mm | Rotation speed, RPM | Ra, µm | Rz, µm | |
| (Pinkowski *et al.*, 2012) | Birch Beech | 2 | | 14.500 | Low values | | |
| (Sütçü and Karagöz, 2013) | Chestnut | 0,25; 0,5; 0,75; 1 | 2; 4; 6 | 12.000; 15.000; 18.000 | 5,0 | | Tungsten carbide-solid straight router bit |
| | Beech | | | | 4,3 | | |
| | Walnut | | | | 3,4 | | |
| (Coșereanu and Cismaru, 2014) | Ash | 0,6; 1; 1,5; 3; 6; 8; 10 | 3 | 12.000; 18.000 | The smallest areas of grain tearing | | Alloy steel |
| | | | 2 | | | | Carbide metal |
| | Linden | 1,5 | 1 | 18.000 | | | |
| | Fir | mici | 2; 3 | 12.000 | | | |
| (Hazir and Koc, 2016) | European Black Pine | 2 | 2,6 | 18.000 | 5,5 | | |
| (Ișleyen and Karamanoglu, 2019) | Beech | 2 | | 18.000 | | | Optimal parameters |
| (Çakiroğlu *et al.*, 2019) | Spruce Chestnut | 5 | | 10.000 | | Low values | |
| | Larix Iroko | 7 | | 18.000 | | Low values | |
| | Spruce Chesnut Larice Iroko | 9 | | 10.000 | | High values | |
| (Hazır and Koc, 2019) | Lebanon Cedar | 2 | | 17.000 | Minimum values | Minimum values | |
| (Paiu *et al.*, 2019) | Spruce | 2 | 3 | 12.000 | The parameters are not optimal | | Ball nose |
| | Poplar plywood | 3 | | | | | |
| | MDF | 3,5 | | 18.000 | | | |
| (Gürgen *et al.*, 2022) | Pine | 3 | | 17.900 | 3,8 | | |

#### *1.3.2. Pyrography*

Laser engraving utilizes a highly focused beam of light to cut or carve a design into a hard material. It offers advantages such as durability, precision, versatility, protection against object damage, and production efficiency.

Laser processing techniques rely on thermal effects (Pearsică *et al.*, 2006). To develop an optimal laser processing technology, it is important to establish corresponding parameters.

In Romanian folk art, pyrography and painting are often combined in decorating wooden objects, resulting in distinct ornaments. Wood species with a homogeneous structure and color are used, and finishing is done with transparent varnishes, oils, or waxes (Cismaru and Coșereanu, 2016).

The aesthetic evaluation of laser engraving on wood has focused on light-colored wood species since the contrast between the pattern and background is more pronounced (Chernykh *et al.*, 2018). Studies have been conducted on the color shades achieved through pyrography with different laser beam intensities (Petru, 2015), the quality of the processed surface, the heat-affected zone, and surface burning (Liu *et al.*, 2020). Furthermore, the effects of laser parameters such as focal distance, cutting speed, and power on wood and wood-based materials have been investigated (Gabdrakhmanov *et al.*, 2019).

Research has highlighted mathematical relationships between wood surface roughness and laser parameters (Gurău and Petru, 2018), as well as changes in wood morphology, chemical structure, and surface properties resulting from laser processing (Kúdela *et al.*, 2022).

#### *1.3.3. Painting*

Furniture painting is a widespread technique in various regions of the world and has a rich history in Egypt, China, Japan, Byzantium, Renaissance Italy, Baroque and Rococo Germany, Switzerland, Hungary, Romania, and Russia (Bucătaru, 1991).

In Transylvania, painted furniture was created manually using stencils or direct painting and featured region-specific decorative motifs from the corresponding period (Negoescu, 2011). Painted furniture could be found in various types of pieces, such as cabinets, dowry chests, and coat racks (Stoica, 1973). Painting and sculpture are closely related to ornamentation and can be combined in different ways (Marc, 2009-2010).

Currently, there is a growing interest in painted furniture, both among contemporary folk artists and in the creations of designers and visual artists. Adding a painted furniture piece to a modern interior combines utility with traditional artistic value adapted to current trends (Pomponiu, 2007).

## CHAPTER 2. THE PURPOSE AND OBJECTIVES OF THE DOCTORAL THESIS

The purpose of the thesis is to perpetuate motifs from the textile heritage by promoting the traditional style in the current development of furniture design, contributing to the preservation of cultural identity.

Based on the purpose of the thesis, the strategy of experimental and theoretical research entails the following specific objectives:

SO1. Identifying the national specificity through the study of form and significance of traditional motifs from the Romanian textile heritage.

SO2. Collecting, selecting, and digitally translating a number of 100 traditional motifs identified in the textile heritage of the Țara Bârsei and its surroundings from museum and private collections.

SO3. Experimental research on the technological possibilities of transposing traditional motifs from the textile heritage through milling on Computer Numerical Control (CNC) machines, varying the processing parameters and wood materials used.

SO4. Experimental research on the possibilities of transposing traditional motifs from the textile heritage through laser engraving, studying color variations based on laser beam power and engraving depth at a microscopic level.

SO5. Implementing the ornamentation method at the level of a business operator.

# CHAPTER 3. DIGITIZATION OF TRADITIONAL MOTIFS FROM THE TEXTILE HERITAGE OF ȚARA BÂRSEI AND SURROUNDINGS

Țara Bârsei is an interethnic space, a historical and ethnographic region in southeastern Transylvania (Fig. 3.1), traversed by the Bârsa, Ghimbășel, and Vulcănița rivers in the southern and central parts, and the Olt river in the north. Numerous historians, ethnographers, anthropologists, and geographers have studied the Bârsa Land, but there is no consensus among them regarding its boundaries. Each delineation has been based on different arguments (Pop, 2011).

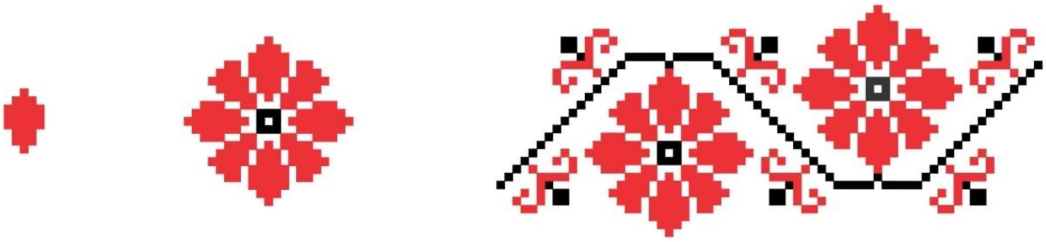

Fig. 3.1. The position of the Țara Bârsei area on the territory of Romania

## 3.1. Traditional Ornamentation

Like in all corners of the world, women in the Romanian region have been sewing and weaving, passing down these crafts from one generation to the next. They did so to clothe themselves, protecting their bodies from cold and sun, but also to convey information about themselves to others: their origin, age, whether they were unmarried, married, or widowed. At the same time, these activities served as a means of subsistence and an artistic expression, thus contributing to the cultural heritage of each country and to the universal heritage.

Traditional motifs "speak" to us about our ancestors, their perceptions of the world and life, their values, and expectations. Traditional ornamentation has been divided (Dunăre, 1979) into three components:

- Ornamental element: the simplest indivisible ornamental part that can exist independently in decoration (leaf, petal, branch, stem, fruit, star) (Fig. 3.2.a).
- Ornamental motif composed of two or more ornamental elements, divisible into ornamental elements from the same thematic group (flower) (Fig. 3.2.b).
- Ornamental composition formed by two or more ornamental motifs, which can be from different thematic and stylistic groups (Fig. 3.2.c).



a b c

Fig. 3.2. Pattern collected from a blouse of a June (young man) from Șcheii Brașovului, private collection: a - ornamental element; b - ornamental motif; c - ornamental composition.

Elements, motifs, and ornamental compositions constitute signs to which people have attributed certain meanings correlated with representations, understandings, significances, symbols, or myths. The signs used are more than simple graphic symbols; they become ornaments when transmitting agents and receivers - as members of a regional or national community - attribute them aesthetic and socio-cultural functions (Dunăre, 1979).

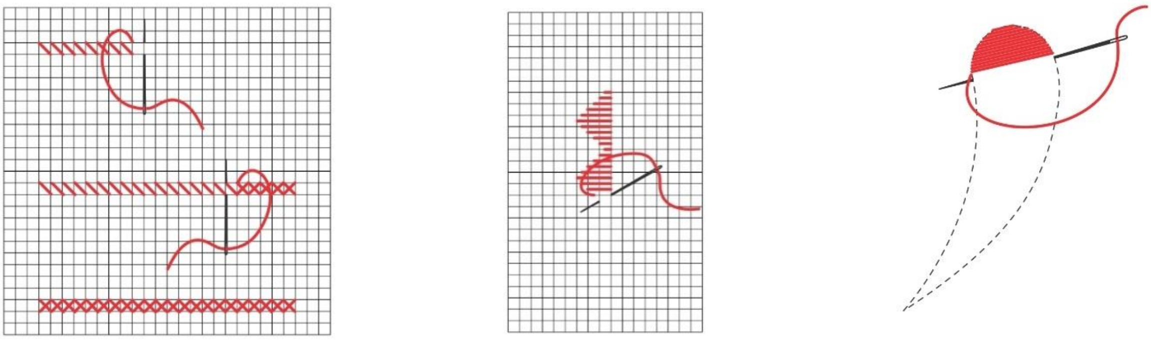
The patterns used for ornamentation reflect the environment in which the folk artist lives, their spiritual beliefs, and their understanding of the construction and functioning of the world. By understanding the meanings and origins of the patterns and symbols in traditional ornamentation, we can appreciate the skill of the creators.

In embroidery, the stitching point or unit is of great importance, as it is through its repetition that elements, motifs, and ornamental compositions are achieved. The original patterns that form the database in this chapter were created through cross-stitch, satin stitch embroidery, or pattern-based satin stitch embroidery.

Cross-stitch is an ancient technique that was widely used not only by Romanians but also by other nationalities in Romania, including the Saxons and Csángós in Țara Bârsei (Dunăre *et al.*, 1974). The simple cross stitch (Fig. 3.3.a) is worked in rows, with two parallel lines. On the front side, diagonal overlapping lines are formed, one from left to right and the other in reverse, from right to left, while on the back side, vertical lines are created.

Satin stitch embroidery (Fig. 3.3.b) is a traditional stitching technique performed in width with closely spaced stitches to fill the entire pattern. This technique is worked on counted threads, with the needle alternately passing above and below the fabric. The backside of the embroidery corresponds to the negative of the ornament.

Pattern-based satin stitch embroidery (Fig. 3.3.c) uses the same type of stitch as satin stitch embroidery but differs in that the pattern is either hand-drawn or copied onto the fabric using indigo. This technique became more popular than satin stitch embroidery and was used as the main technique in embroideries made after 1900.



a b c

Fig. 3.3. Stitching techniques: a - Cross-stitch; b – Embroidery on threads; c - Pattern-based satin stitch embroidery.

### 3.2. Research Methodology

The working method consisted of:

- Taking photographs of each model or collecting them from textile object owners.
- Importing the JPG files into the *CorelDRAW* program.
- Drawing the model on a grid of squares for models executed using cross-stitch or embroidery on threads (Fig. 3.4.), or tracing the outline of the image for models executed using embroidery on the drawing (Fig. 3.5.), with closed or open contours.
- Coloring the closed contours.

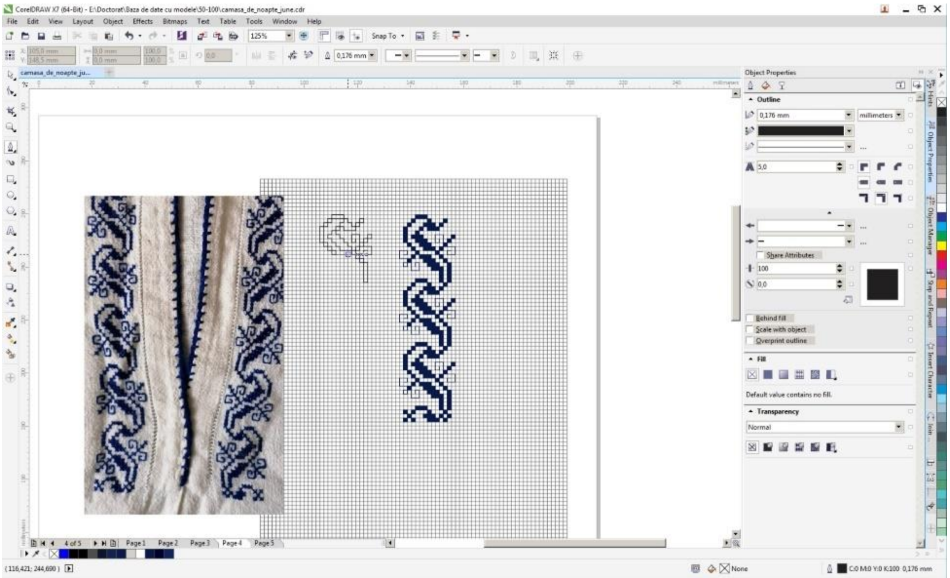


Fig. 3.4. Drawing of models executed using cross-stitch or embroidery on threads.

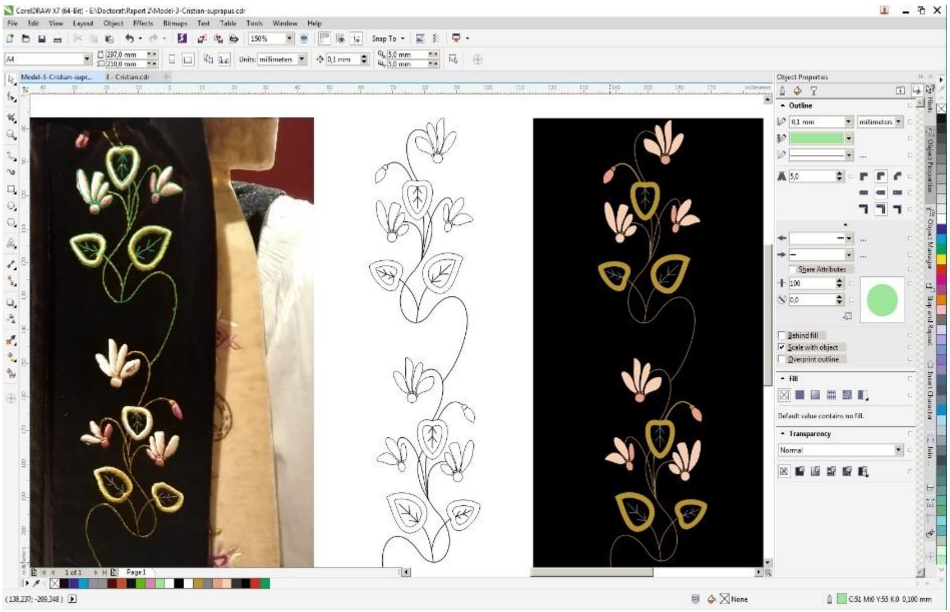


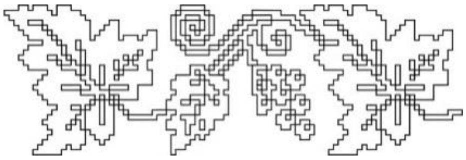
Fig. 3.5. Drawing of models executed using embroidery on the drawing.

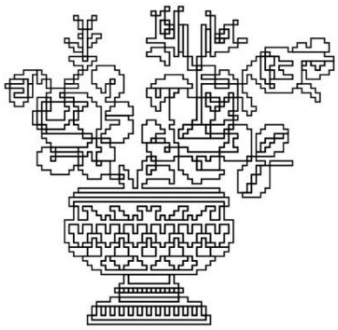
## 3.3. Database of Traditional Motifs from the Textile Heritage of Țara Bârsei Subjected to Digitization

### *3.3.1. Digitized Traditional Patterns*

The database included in the thesis consists of 100 patterns. Below is a selection of these patterns, specifically the ones that have been transferred onto wood through CNC milling or laser engraving.

Table 3.1. Traditional cross-stitch patterns

| | **Model 2** | | |
|---|---|---|---|
| 1 | *Origin* | | |
| | June's blouse from Şcheii Braşovului - Private collection | | |
| 2 | *Method of execution* | 3 | *Motif* |
| Cross-stitch | | Grapevine | |
| 4 | *Photography* | | |
|  | | | |
| 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving | | |

| | **Model 8** | | | | |
|---|---|---|---|---|---|
| 1 | *Origin* | | | | |
| | June's blouse from Şcheii Braşovului - Private collection | | | | |
| 2 | *Method of execution* | 3 | *Motif* | | |
| Cross-stitch | | The flower vase | | | |
| 4 | *Photography* | 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving | | | | |

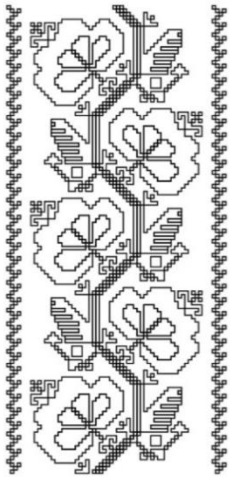
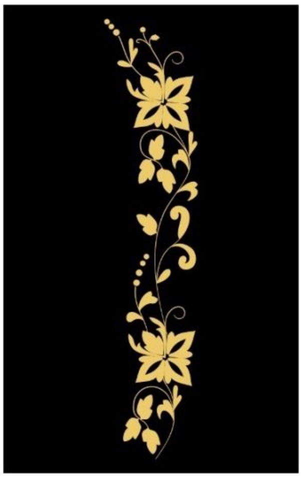
| | | | | | |
|---|---|---|---|---|---|
| | **Model 33** | | | | |
| 1 | *Origin* | | | | |
| | Ie from the Bran area - IE Vie collection | | | | |
| 2 | *Method of execution* | | 3 | *Motif* | |
| Cross-stitch | | | Shamrock leaf, Water wave, Fir tree leaf | | |
| 4 | *Photography* | 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving | | | | |

Table 3.2. Traditional patterns executed in embroidery on the drawing

| | | | | | |
|---|---|---|---|---|---|
| | **Model 64** | | | | |
| 1 | *Origin* | | | | |
| | Saxon women's costume bow from Țara Bârsei - Brașov Ethnography Museum | | | | |
| 2 | *Method of execution* | | 3 | *Motif* | |
| Embroidery on the drawing | | | Phytomorphic | | |
| 4 | *Photography* | 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving, Painting | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | **Model 65** | | | | |
| 1 | *Origin* | | | | |
| | Saxon women's costume bow from Țara Bârsei - Brașov Ethnography Museum | | | | |
| 2 | *Method of execution* | | 3 | *Motif* | |
| Embroidery on the drawing | | | Phytomorphic | | |
| 4 | *Photography* | 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving, Painting | | | | |

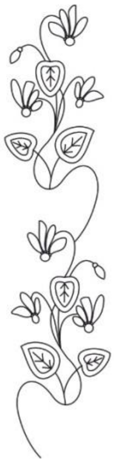
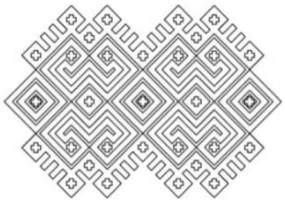
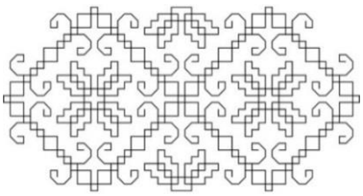
| | | | | | |
|---|---|---|---|---|---|
| | **Model 87** | | | | |
| 1 | *Origin* | | | | |
| | Saxon women's costume bow from Cristian village - Brașov Ethnography Museum | | | | |
| 2 | *Method of execution* | | 3 | *Motif* | |
| Embroidery on the drawing | | | Phytomorphic | | |
| 4 | *Photography* | 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving, Painting | | | | |

Table 3.3. Traditional patterns executed in embroidery on threads

| | | | |
|---|---|---|---|
| | **Model 94** | | |
| 1 | *Origin* | | |
| | Ie from Veneția de Sus, Făgăraș area - Private collection | | |
| 2 | *Method of execution* | 3 | *Motif* |
| Embroidery on threads | | Ram's horns | |
| 4 | *Photography* | | |
|  | | | |
| 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving | | |

| | | | |
|---|---|---|---|
| | **Model 100** | | |
| 1 | *Origin* | | |
| | Ie from Dumbrăvița Village - IE Vie collection | | |
| 2 | *Method of execution* | 3 | *Motif* |
| Embroidery on threads | | The star | |
| 4 | *Photography* | | |
|  | | | |
| 5 | *Drawing* | 6 | *Contour drawing* |
|  | |  | |
| 7 | *Possibilities for development in furniture:* CNC milling, Laser engraving | | |

In Tables 3.1, 3.2, and 3.3, some of the 100 collected patterns are presented, originating from localities grouped into ten regions based on proximity (Fig. 3.6), gathered from the Ethnography Museum of Brașov, the Urban Civilization Museum of Brașov, the County History Museum of Brașov, the Codlea Traditions Museum, the Museum in Odorheiul Secuiesc, from private collections, or from individuals (Fig. 3.7). The patterns were created using cross-stitch technique, full embroidery on drawing, or full embroidery on thread (Fig. 3.8).

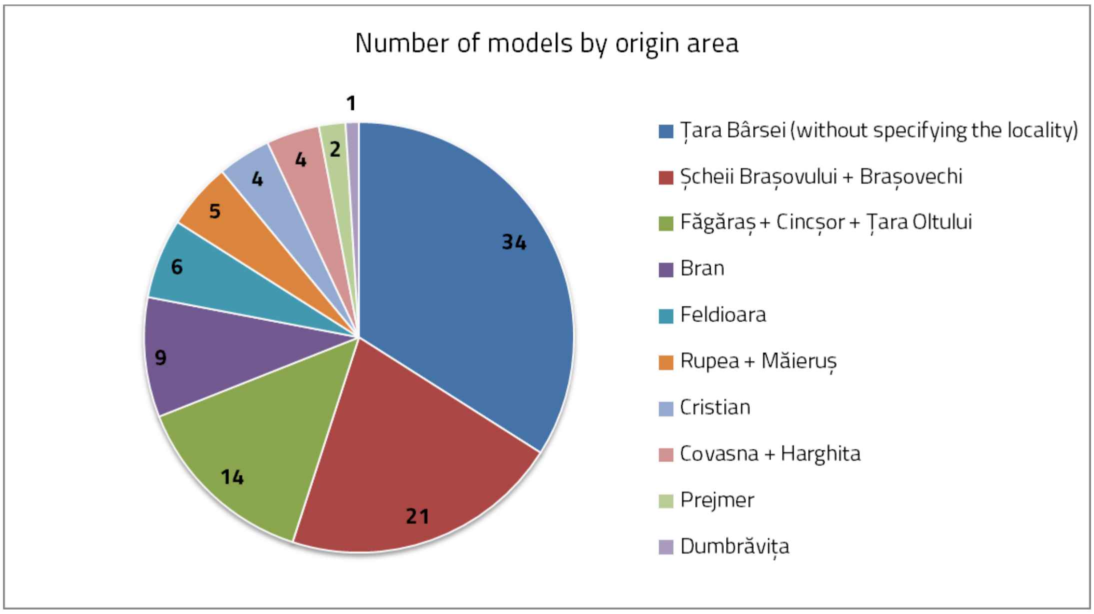



Fig. 3.6. The distribution of patterns in the database based on the textile object's origin zone.

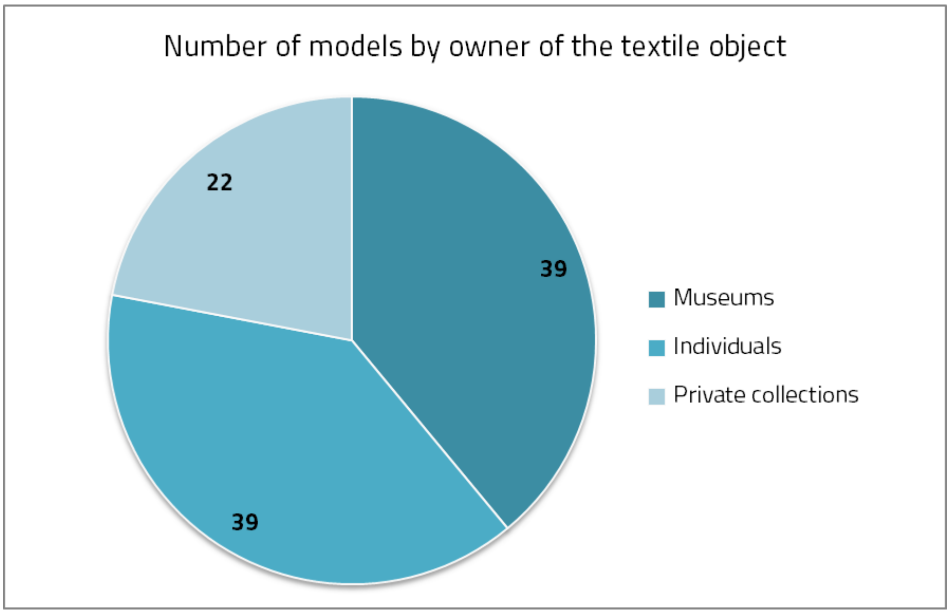



Fig. 3.7. Distribution of patterns in the database based on the owner of the textile object.

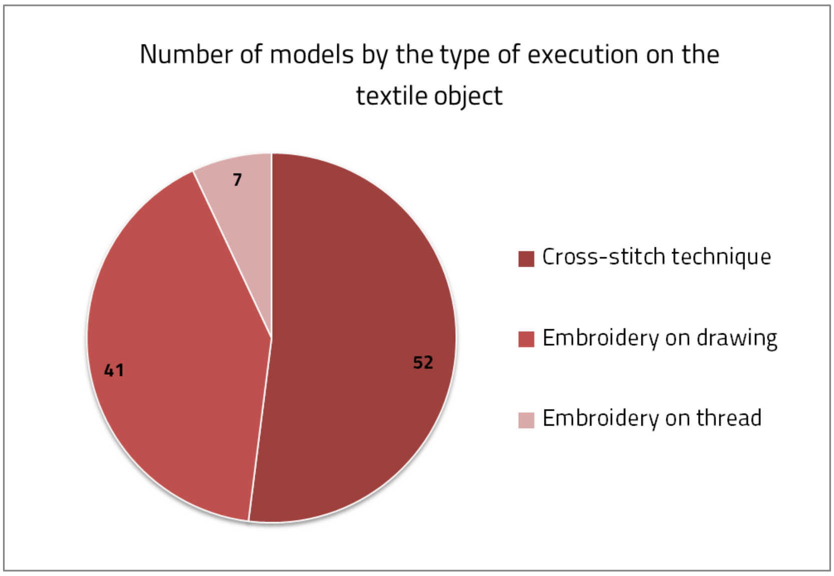



Fig. 3.8. Distribution of patterns in the database based on the type of execution on the textile object.

### *3.3.2. Meaning and Symbolism of Traditional Motifs*

The embroidered motifs first served the purpose of protecting those who used them and only then of ornamenting the object. The symbolism of the motifs found in the database with the 100 patterns is presented in the thesis; below is the symbolism for the aforementioned motifs.

*Ram's horns* - Symbolize power, strength, and masculine energy, associated with virility and the principle of fertility (Semne cusute, 2021).

*Fir tree leaf* - The fir tree, associated with the tree of life, represents the backbone of the world (Semne cusute, 2021).

*Phytomorphic motif* - The symbolism of flowers is characterized by two aspects: their essence and form. The flower, by its nature, is considered a symbol of transition, spring, and beauty (Cirlot, 2001).

*Star* - Considered the eyes of the sky, the children of the moon and the sun, as well as symbols of individual destiny (Moisei, 2015).

*Shamrock* - Suggests the magical number three, which is present in many ritual practices and serves to protect human life. The four-leafed shamrock is a lucky symbol (Antonescu, 2016).

*Water wave* - Flowing waters symbolize a passage, a test that we must go through, representing the flow of life and the passage of time (Semne cusute, 2021).

*Flower vase* - Represents a stylized version of the Tree of Life symbol, symbolizing the utopian desire for "youth without old age and life without death" (Antonescu, 2016).

*Grapevine* - Symbol of womanhood and a plant with sacred powers (Antonescu, 2016). It represents the symbol of immortality, whose essence is sheltered in the vine that greens, blossoms, and bears fruit in the summer, and in barrels during winter (Ghinoiu, 2013).

# CHAPTER 4. EXPERIMENTAL RESEARCH ON POSSIBILITIES OF TRANSPOSING TRADITIONAL MOTIFS ONTO FURNITURE SURFACES THROUGH CNC MILLING

## 4.1. Wood Species Used in the Research

For the research, five different wood species were selected, including both softwood and hardwood species, to cover a range of species with uniform light color (spruce and sycamore) and darker color (beech), as well as species that exhibit color variations due to annual rings (larch) and species with large pores arranged in a typical ring pattern (oak). Additionally, some bibliographic studies (Cismaru *et al.*, 1993), (Cismaru, 2003), (Petru, 2020) were considered for the characterization of the selected species.

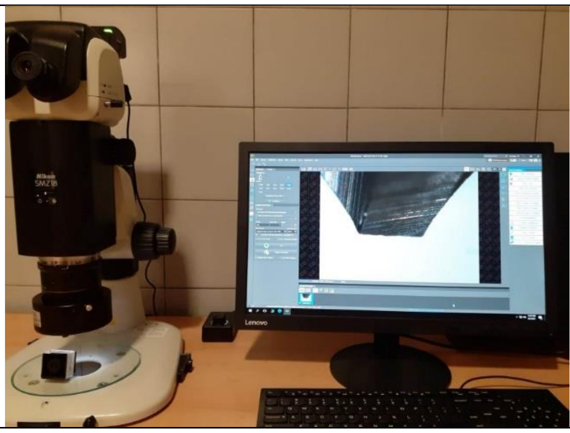
In the preliminary research, 18 mm MDF (Medium-Density Fiberboard) was used as a homogeneous and versatile material that is easy to process and can be finished through enamel coating, veneering, lamination, or melamine treatment.

## 4.2. Equipment and Methods Used in the Research

The equipment used for the research in this doctoral thesis is part of the equipment of the *Faculty of Furniture Design and Wood Engineering* (FDMIL), specifically the *Laboratory of Numerical Control Technology in the Wood Industry*, and the *Research and Development Institute of Transilvania University of Brașov* (ICDT), as presented in Table 4.1.

Tabel 4.1. Equipment used in the research of ornament processing through milling

| Operation | Equipment | Manufacturer | Software |
|---|---|---|---|
| Milling | 3-axis CNC machine ISEL GFV type | Eiterfeld, Germany | CAM Aspire, Vectric |

| Operation | Equipment | Manufacturer | Software |
|---|---|---|---|
| Measurement of surface quality | MarSurf XT20, equipped with an MFW 250 scanning probe with a tracking arm in the range of ±750 μm and a stylus with a tip radius of 2 μm and a tip angle of 90° | MAHR Göttingen GMBH, Göttingen Germany | MARWIN XR20, provided by the manufacturer |
| |  | | |
| Microscopic investigation | NIKON SMZ 18 stereo microscope, with a magnification ratio of 18:1 and a magnification range between 22.5 x and 405 x. Magnifications used in the research: 22.5 x, 120 x. | Nikon Instruments, Melville, USA | NIS-Elements Imaging, used for image capture, measurements, and analysis. |
| |  | | |

### 4.3. Preliminary Experimental Research for Choosing the Suitable Tooling and Milling Method for Transposing Textile Heritage Motifs onto Wooden Surfaces

The methodology used in the research is presented in Fig. 4.1.

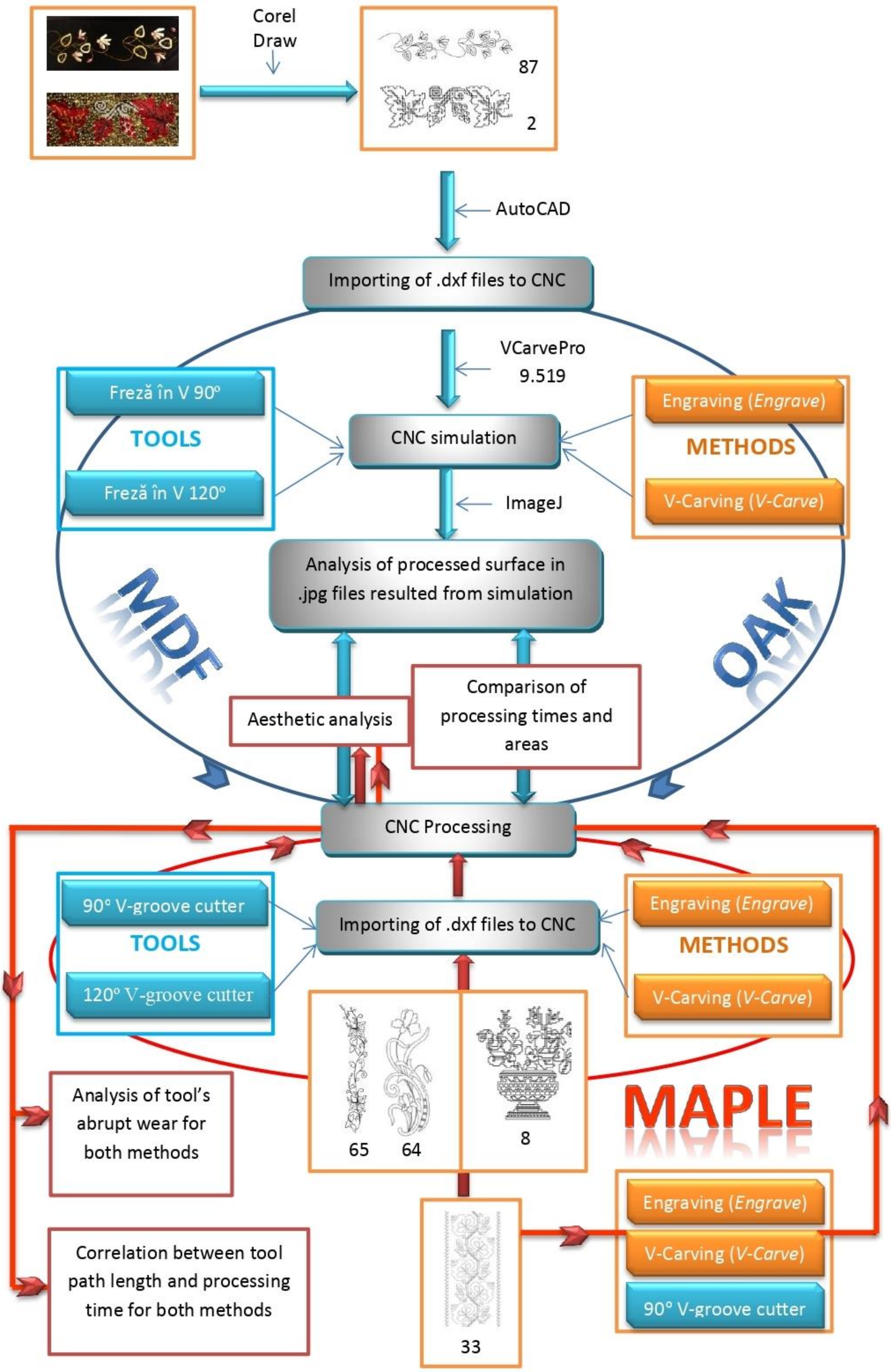
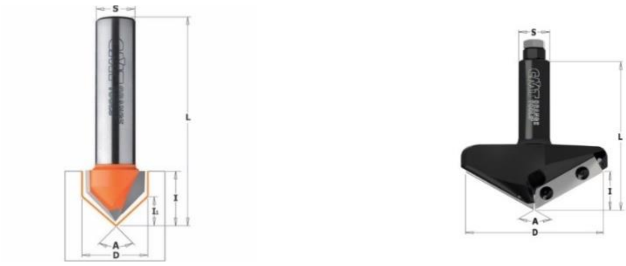



Fig. 4.1. Research methodology for CNC milling.

The simulation software allows for two types of processing methods. Engraving is the processing method with a constant cutting depth (2 or 3 mm) for contours and can be applied to both closed and open contours of the design. V-Carving is the processing method with a variable cutting depth for the surface (between 1 mm and 3 mm) and a constant depth for the contour (2 or 3 mm). The second method can only be applied to closed contours of the designs. The two methods can be combined for small contour lines.

The selected tools are V-groove cutters with angles of 90° and 120°, suitable for engraved surfaces, which operate at higher feed rates, have a reduced processing depth, and shorter processing times.

The chosen tools for CNC milling are the CMT Orange Tools 915.817.11 with a 90° angle (Fig. 4.2.a) and the CMT Orange Tools 663.120.11 with a 120° angle (Fig. 4.2.b).



a b

Fig. 4.2. CNC milling cutters used: a - with a 90° angle; b - with a 120° angle.

#### *4.3.1. Experimental Research on CNC Milling of Traditional Motifs on Oak Wood (Quercus robur L.) and MDF*

For this study, two patterns were selected (Fig. 4.3) from the two types of textile realization (embroidery and cross-stitch). The first one (Fig. 4.3.a) is a floral motif embroidered on a black velvet ribbon from the costume of a married Saxon woman from Cristian (a village near Brașov). The second one (Fig. 4.3.c) was made using the cross-stitch technique and comes from a shirt in the Şchei neighborhood of Brașov.

The patterns were chosen with a high level of complexity to be able to apply both engraving (*Engrave*) and carving (*V-Carve*) methods.

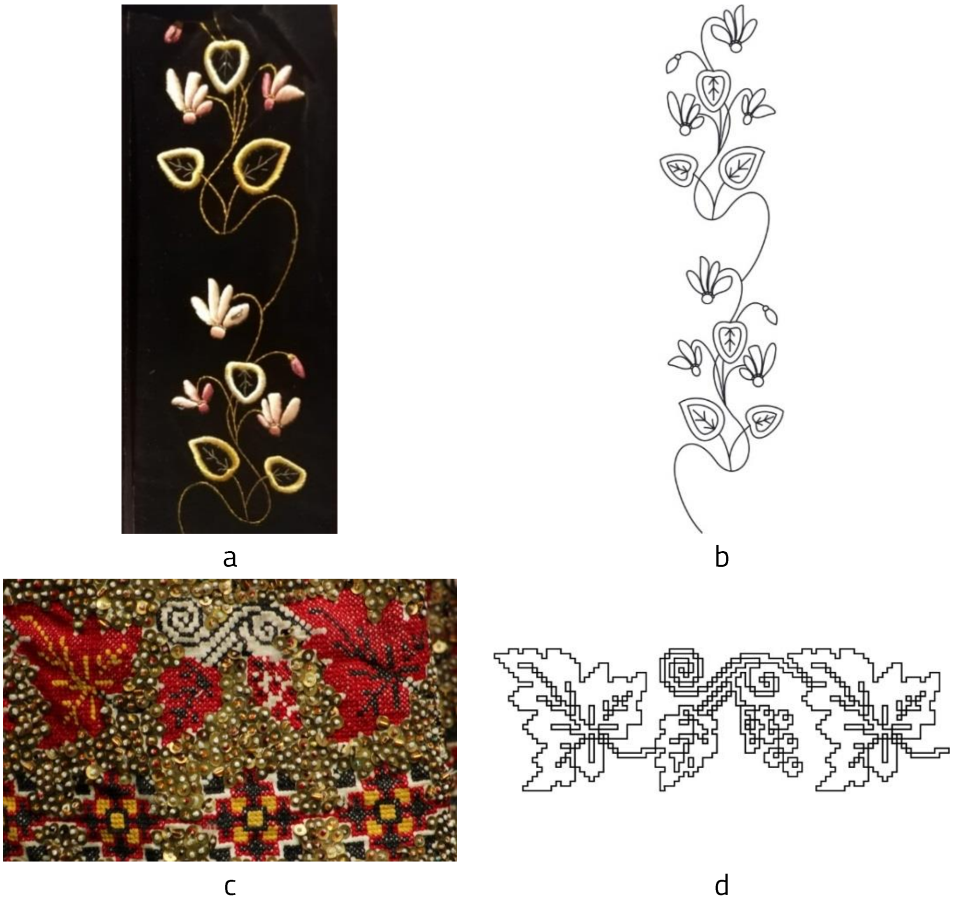



Fig. 4.3. Traditional motifs from textile objects in the Țara Bârsei: a - pattern 87; b - digitized pattern 87; c - pattern 2; d - digitized pattern 2.

The traditional patterns drawn in digital format (Fig. 4.3.b and d) were CNC milled on oak (*Quercus robur* L.) and MDF using the milling cutters from Fig. 4.2. and the two processing methods (*Engrave* and *V-Carve*), with a rotation speed of 12,000 rpm, a milling depth of 2 mm, and a feed rate of 3 m/min.

The experimental design was planned using *XLSTAT* software, developed by Addinsoft, based on the Taguchi experimental design for 4 factors and 2 levels. The available options were 8, 12, 16, or 32 experiments. To compare all the variations, the experimental design with 16 experiments was chosen, and an additional 4 experiments were added, resulting from the combination of the two methods.

For aesthetic purposes, a visual analysis of the processed ornaments was conducted. The images of the milled ornaments were later analyzed using *ImageJ*, an open-source image processing program (ImageJ.net, 2021), which identifies the patterns as objects, selects their contours, and returns a mask image that retains only the objects of interest. Together with the mask image, the software provides numerical data in a spreadsheet about the measured objects, such as the area and perimeter of each object, the total and average area of the objects, the percentage and number of objects detected in an image (Gurău *et al.*, 2010).

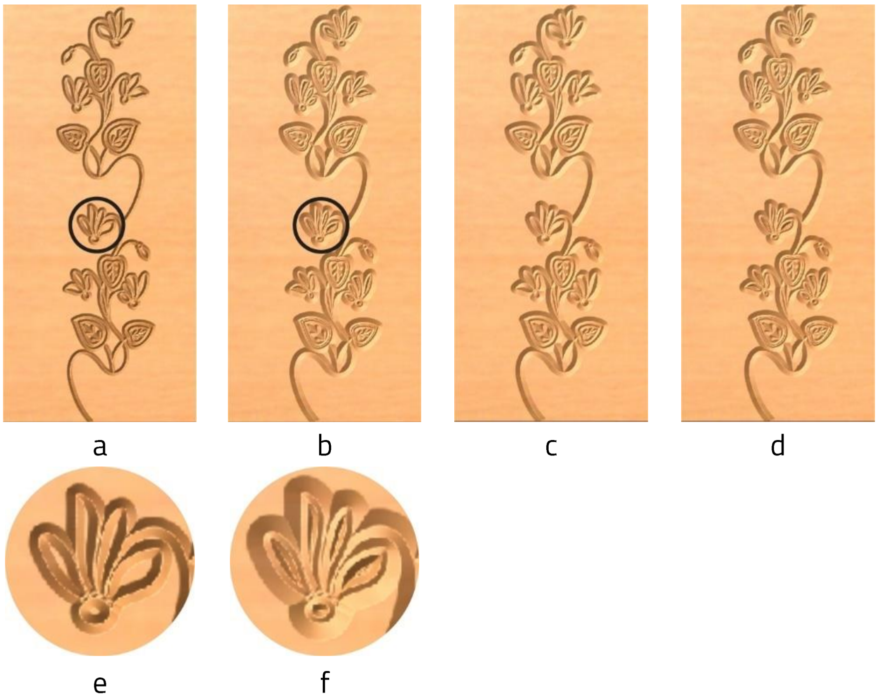



Fig. 4.4. Simulation results for Model 87: a - *Engrave* 90°; b - *V-Carve* 90°; c - *Engrave* 120°; d - *V-Carve* 120°; e - Detail for *Engrave* 90°; f - Detail for *V-Carve* 90°.

The simulation of the first model using the *Engrave* and *V-Carve* processing methods, as well as the two types of V-shaped tools with 90° and 120° angles, resulted in the images shown in Fig. 4.4.

The simulation results revealed slight differences in the details of the first ornament (Model 87) when using the *Engrave* and *V-Carve* processing methods. The highlighted details in Fig. 4.4 demonstrate these differences on the flower of the ornament, but not on the leaves. The ornament engraved with a 90° angle appears cleaner and finer compared to the others. When using the *Engrave* method, the results showed only differences in the width of the processed areas, which were wider when using the V-shaped tool with a 120° tip angle. For the *V-Carve* methods, no visible differences were observed in the simulation results between the two different tools.

A similar approach was applied to the grape cluster and leaves ornament (Model 2).

At first glance, the simulation provides a good idea of how the motif would look on the processed surface with each applied method. However, a single recommendation for a specific method to be applied in the processing of two different motifs cannot be made at this stage.

Compared to MDF, the ornaments processed on oak wood exhibited burn marks, fiber breakage, and wood cracking, especially when applying the *V-Carve* method and the combined method applied to Model 2, with the grape cluster and vine leaf.

The material removed from the surface and the processing time are important aspects in wood processing as they are related to tool wear and productivity.

To calculate the processed material area, ImageJ analysis was used for the ornaments processed on MDF panels in all variations.

The correlation between the processed area and processing time for each model and variation in the experimental design is presented in the diagram in Fig. 4.5. The *Engrave* method was faster than all other methods, regardless of the tool used. Engraving with the 120° angled tool generally removed more surface material compared to other processing methods and required shorter processing times than the *V-Carve* method.

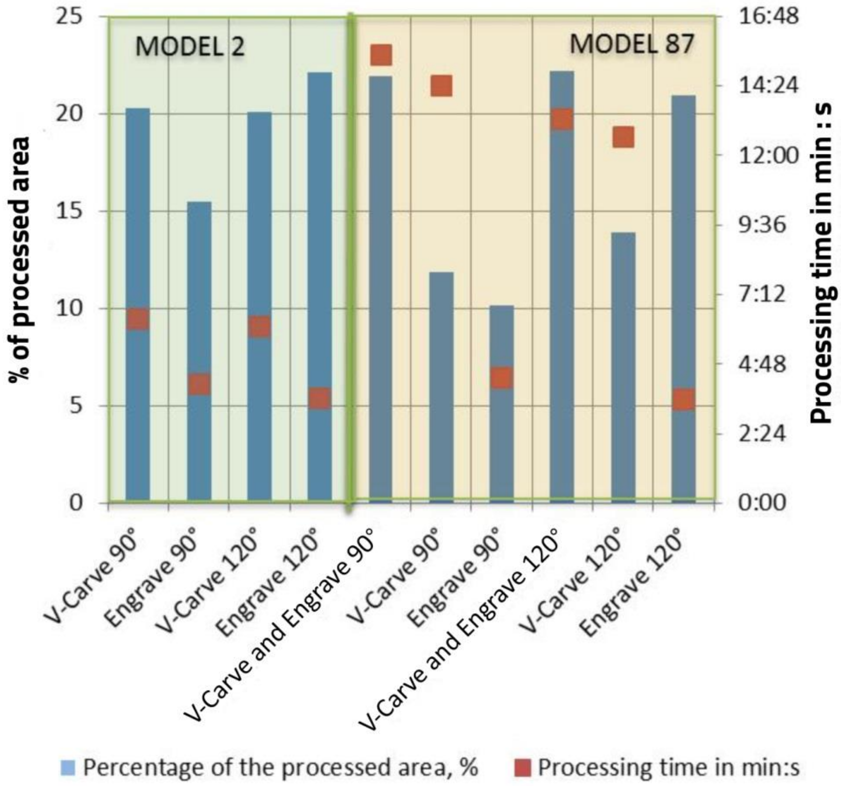



Fig. 4.5. Correlation between processed area and processing time for Model 2 and Model 87.

The general conclusion of this research is that each type of ornament requires an individual analysis to determine the most suitable processing method, material, and tool. MDF has shown the best surface quality and exact reproduction of both types of motifs, compared to solid oak wood.

#### *4.3.2. Experimental Research on CNC Milling of Traditional Motifs on Maple (Acer pseudoplatanus L.)*

Building upon the conclusions drawn from the research presented in Sub-subsection 4.3.1, further experimental investigations were conducted on maple wood, a species known for its uniform structure and lower density compared to oak wood. Maple is recommended for carving works and ornamentation. This time, a more complex motif, stitched using cross-stitch technique, was chosen to allow for a more detailed analysis of the wood quality when processed using the *V-Carve* method.

The selected motif contains larger areas with closed contours, which are intended for a more thorough assessment of the quality of the wood when carved using the *V-Carve* method.

Furthermore, an additional evaluation analysis of tool wear, influenced by the tool's processing path for wood material removal, was considered based on the applied method: engraving (*Engrave*) or carving (*V-Carve*), using a 90° angle cutter. According to the previous conclusions, this cutter angle provides a more accurate transposition of the pattern onto the wooden surface.

For this analysis, motif number 33 (Fig. 4.6.) was selected from the database of traditional motifs from textile heritage presented in Table 3.1. This motif offers not only large areas with closed contours but also a noticeable contrast between two colors, namely burgund and beige.

The contour of motif 33 (Fig. 4.6.b) was CNC-machined using two methods: engraving (*Engrave*) with a constant depth of 3 mm, applied to both closed and open lines, and carving (*V-Carve*) applied only to closed lines with a variable depth ranging from 1 mm to 3 mm for the surface and a depth of 3 mm for the contour. The other milling parameters were set as follows: rotation speed of 15,000 rpm and feed rate of 6 m/min. These milling parameters were chosen based on recommendations for wood species with densities similar to maple wood in a comprehensive study (Çakiroğlu *et al.*, 2019), which indicated a rotation speed of 14,000 rpm and a feed rate of 7 m/min for the lowest Rz roughness parameter value.

For the experimental research, 20 maple panels measuring 300 mm x 200 mm x 11 mm were used, with a moisture content of 11% and an average density of 615 kg/m$^3$.

a b

Fig 4.6. Model 33 from the database of digitized motifs: a - photograph of the textile object; b - contour of the ornament, used for milling on maple wood.

The chosen tool was the CMT Orange Tools 915.817.11 with a 90° angle (Fig. 4.7, Fig. 4.8). These two-edge cutting tools provide a wide range of possibilities for wood processing, delivering clean cuts. They are made from the high-strength Fatigue Proof® steel with tungsten carbide-tipped cutting edges (CMT Orange Tools).


Fig. 4.7. Zone W of investigation the wear of the tool cutting edge (Lungu *et al.*, 2021c).

To study the abrupt wear of the tool, the 20 panels were processed using the ISEL GFV CNC machine. For each panel, the *Engrave* method was applied on one side, and *V-Carve* on the other side, using two new tools, one for the *Engrave* method and the other for the *V-Carve* method.


Fig. 4.8. Zone W rotated by 90° of investigation the wear of the tool cutting edge (Lungu *et al.*, 2021c).

The toolpath was automatically calculated by the *Linux CNC* software version 2.7.0.

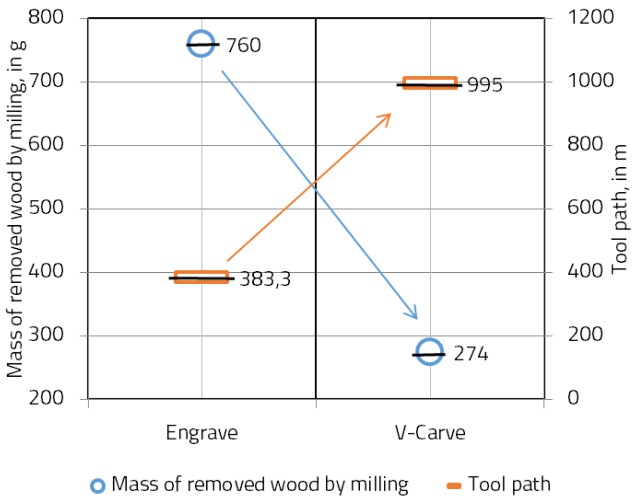
The investigation of the ornaments obtained on wood was carried out by comparing the surfaces processed using the two milling methods, *Engrave* and *V-Carve*, from two perspectives: aesthetic and qualitative. The wood mass loss after CNC processing of the ornaments with the two methods was also determined.

Stereomicroscopic investigation revealed that wear occurred after processing the ornaments on the 20 panels.

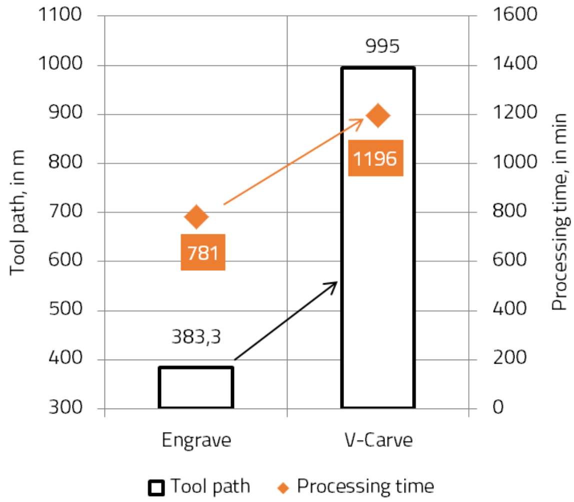
The distance traveled by the milling cutter for ornament processing, calculated by the *Linux CNC* software, was 19,165.4 mm for the *Engrave* method and 49,741.4 mm for the *V-Carve* method in CNC milling. Calculating the total length of the toolpaths for the 20 processed ornaments resulted in a route of 383.3 m for the engraved ornament and 994.8 m for the carved variant. Similar research on Aleppo pine (*Pinus Halepensis* L.) concluded that edge degradation occurred at a cutting length of 850 m with abrupt wear at approximately 200 m (Aknouche *et al.*, 2009).

It was observed that in the *Engrave* method, wear affects the cutting edge area more, while in the *V-Carve* method, the percentage of wear on the tool tip is higher. This can be explained by the different contact areas between the tools and wood for the two cases, with the difference being in the interior surface of the ornament, where the cutting depth varies between 1 mm and 3 mm, and the tool tip is involved in the milling process.

The correlations between the calculated toolpath lengths for the 20 processed ornaments, corresponding processing times, and the masses of removed wood are presented in Fig. 4.9.




a




b

Fig. 4.9. Comparison between Engrave and V-Carve methods applied to CNC routing of ornament on maple wood surface: a - correlation between the mass of removed wood and tool path length; b - correlation between tool path length and processing time.

During the *V-Carve* method, it was observed that in areas where the processing depth is only 1 mm, partial processing of the pattern occurs if the panel is not perfectly flat. Therefore, a mandatory condition for CNC milling using this method is panel calibration for solid wood.

Similar to the experiment on oak wood and MDF panel, for CNC milling on maple wood, two models from the textile heritage were chosen, sewn through full embroidery. These models are Model 64 (Fig. 4.10.c and Fig. 4.11.c) and Model 65 (Fig. 4.10.b and Fig. 4.11.b). Additionally, a highly complex traditional motif obtained through cross-stitching technique was selected, which is Model 8 (Fig. 4.10.a and Fig. 4.11.a). This motif alternates between small-sized closed contour areas and larger closed contour areas to test if the *V-Carve* method can be applied in this case as well, similar to motif number 33 analyzed earlier.

a

b

c

Fig. 4.10. Motifs subjected to the second research: a - Model 8; b - Model 65; c - Model 64.

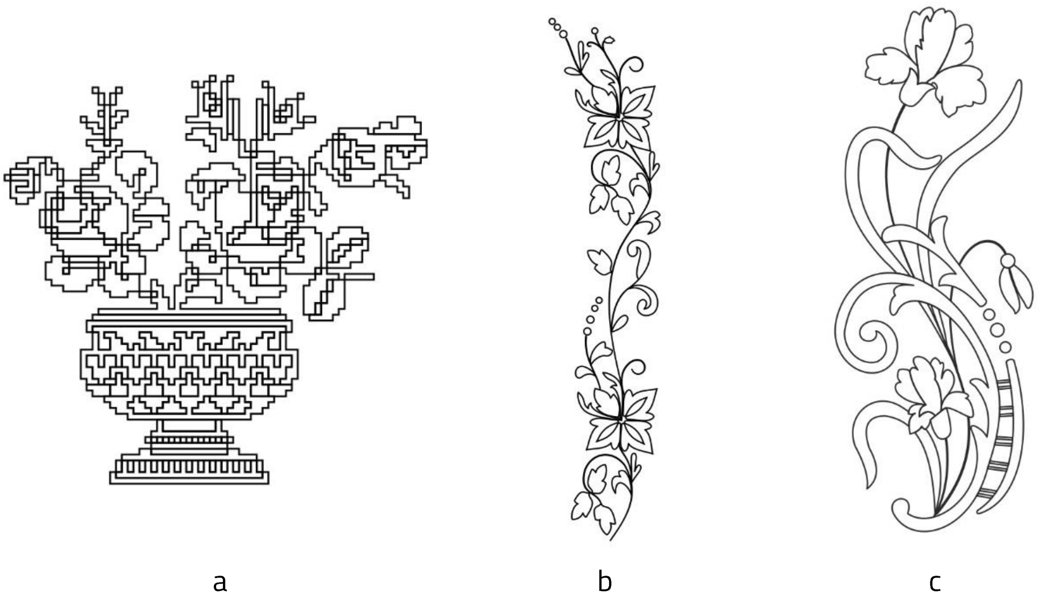



Fig. 4.11. The digitization of the models subjected to the second research: a - model 8; b - model 65; c - model 64.

The simulation process showed that the *V-Carve* method was not suitable because the patterns were not fully processed due to the presence of open contours in the design. Using a combination of *V-Carve* and *Engrave* methods resulted in overcrowded ornaments.

Applying the *Engrave* method for actual CNC processing resulted in the images shown in Fig. 4.12.a1, Fig. 4.13.a1, and Fig. 4.14.a1 for engraving with a 90° angle mill, and Fig. 4.12.b1, Fig. 4.13.b1, and Fig. 4.14.b1 for engraving with a 120° angle mill. After processing the panels, by analyzing the details presented in Fig. 4.12.a2 and b2, Fig. 4.13.a2 and b2, and Fig. 4.14.a2 and b2, noticeable differences were observed when using V-shaped mills with angles of 90° and 120°.

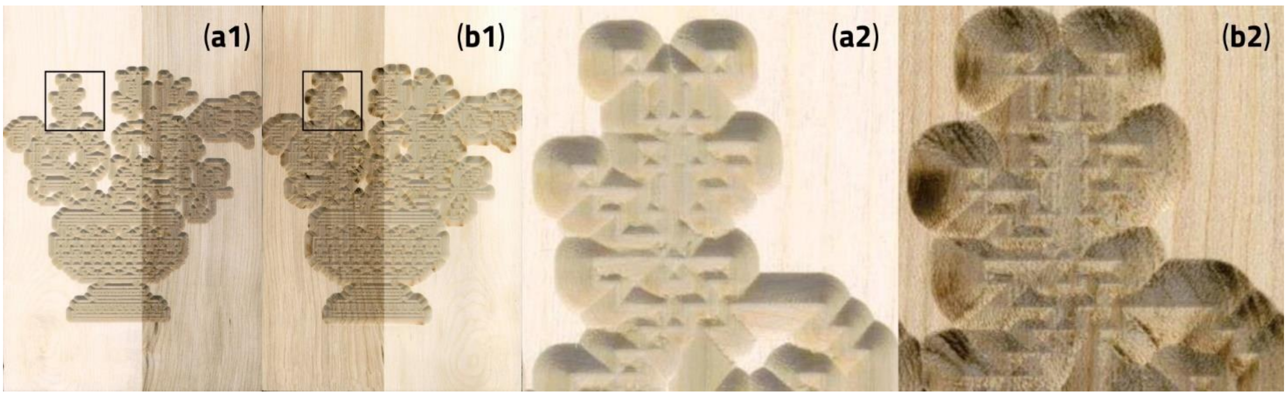



Fig. 4.12. CNC milling of model 8: a1 - *Engrave* 90°; a2 - Detail for *Engrave* 90°; b1 - *Engrave* 120°; b2 - Detail for *Engrave* 120°.

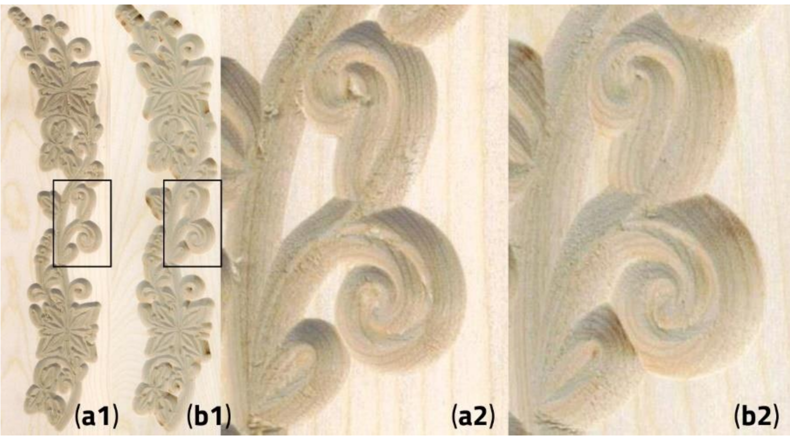



Fig. 4.13. CNC milling of model 65: a1 - *Engrave* 90°; a2 - Detail for *Engrave* 90°; b1 - *Engrave* 120°; b2 - Detail for *Engrave* 120°.

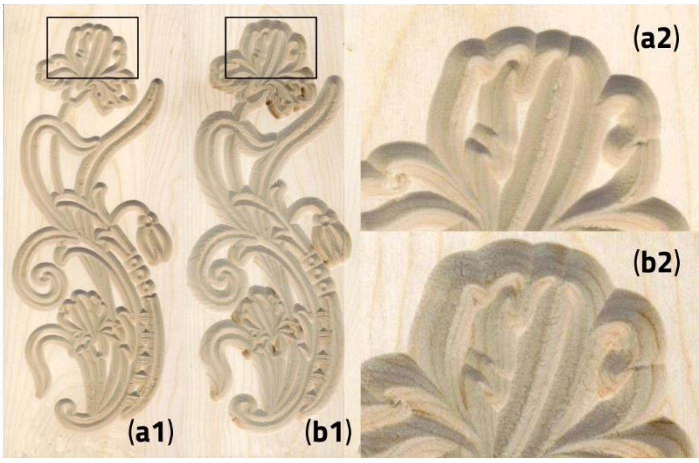



Fig. 4.14. CNC milling of model 64: a1 - *Engrave* 90°; a2 - Detail for *Engrave* 90°; b1 - *Engrave* 120°; b2 - Detail for *Engrave* 120°.

The milling simulation software for CNC machines provides the possibility to select appropriate tools and methods and eliminate unsatisfactory options, as was the case with complex ornaments where there are alternating closed, semi-closed, and open contours, namely traditional motifs 8, 64, and 65. For these, the simulation indicated that the *V-Carve* processing method was unsatisfactory.

Processing on the wooden surface provides a complete aesthetic image and surface quality. In the case of complex ornaments, where the digitization of traditional motifs required the creation of drawings with closed, semi-closed, and open contours, milling through *V-Carve* carving method is not recommended, and the *Engrave* method results in overcrowding of ornament lines, making the perception of the ornament difficult. For this type of complex models, the application of another ornamentation technology is necessary, and in this regard, the possibility of using laser engraving will be studied in a subsequent chapter.

### 4.4. The Influence of Milling Angle in Relation to the Wood Grain Direction on the Surface Quality of Wood

During the CNC milling of ornaments in the experimental research presented in Subchapter 4.3, it was observed that raised fibers and ruptures occur in certain processed areas, both on the curved and straight contours of the model.

In order to compare the behavior of the five selected wood species, the influence of milling direction relative to the longitudinal wood grain will be studied. The evaluation will focus on the surface quality of milled surfaces at angles of 0°, 15°, 30°, 45°, 60°, 75°, and 90° in relation to the fiber direction. This evaluation will be conducted at a macroscopic level for curved contours, and by measuring roughness parameters for straight-line processing.

#### *4.4.1. Study on the Quality of the Machined Surface in Contour Milling*

Wood panels from the five selected species mentioned in subsection 4.1, with dimensions of 300 mm × 200 mm × 18 mm, and moisture content ranging from 7.3% to 11.2%, were calibrated using abrasive with a grain size of 60 to ensure surface flatness within the tolerance range of ± 0.15 mm. These panels were used as a base support for CNC milling of a circle with a radius of 90 mm.

The study involved visually examining the quality of the milled surface, taking into account the tool position relative to the wood fiber direction. This position was calculated as an angular value based on the central angle of the circle.

The aim of the study was to visualize defects that occur during the machining process on the CNC-milled circles. These qualitatively defective areas were marked on the circle based on the central angle, with blue indicating negative angles and red indicating positive angles (Fig. 4.15).

Oak n = 12,000 rpm, u = 3 m/min

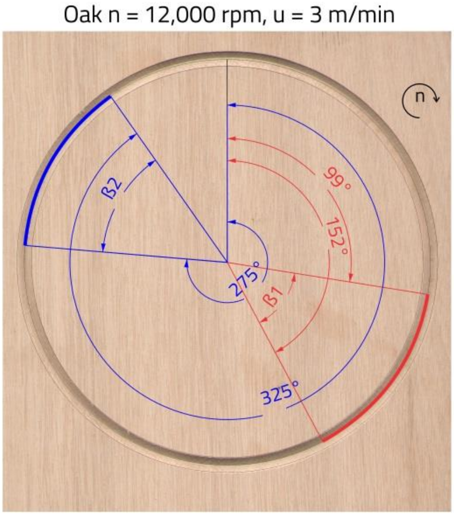
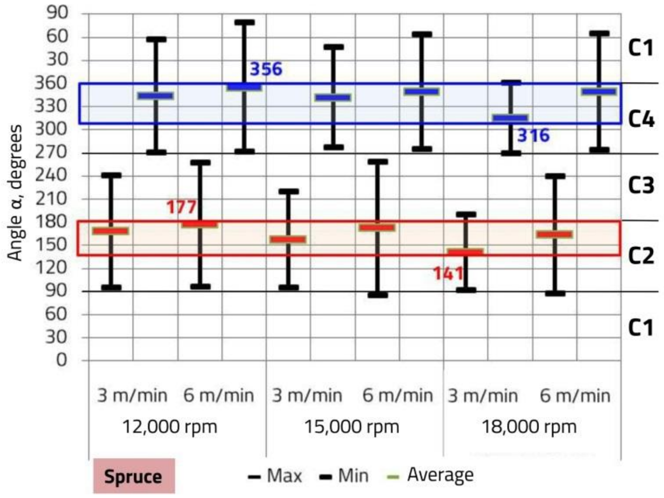
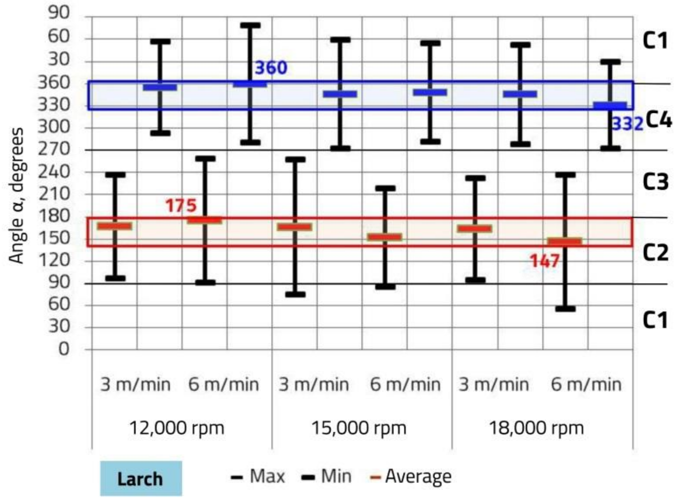



Fig 4.15. Scanned image of the oak panel with the CNC-milled circle on the wood surface, highlighting the visible areas where machining defects occur.

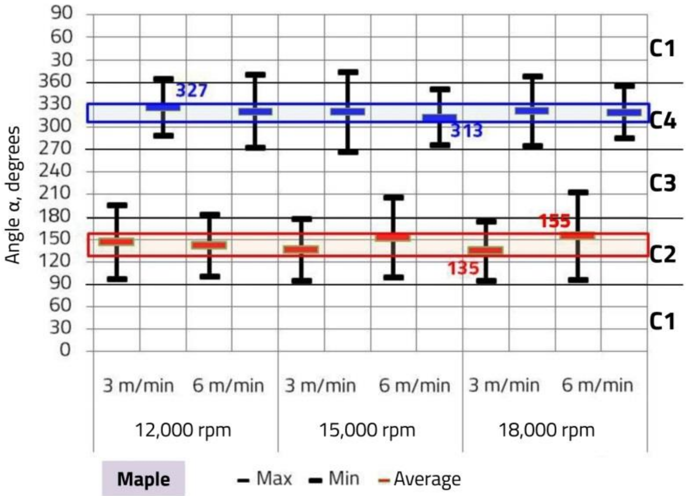
In Fig. 4.15, an example is presented for oak, where the circle was CNC-milled in a clockwise direction. The size of the qualitatively affected area is equal to the arc length (L) in millimeters, calculated by multiplying the radius of the circle (r) in millimeters by the central angle of the circle (ß) in degrees.



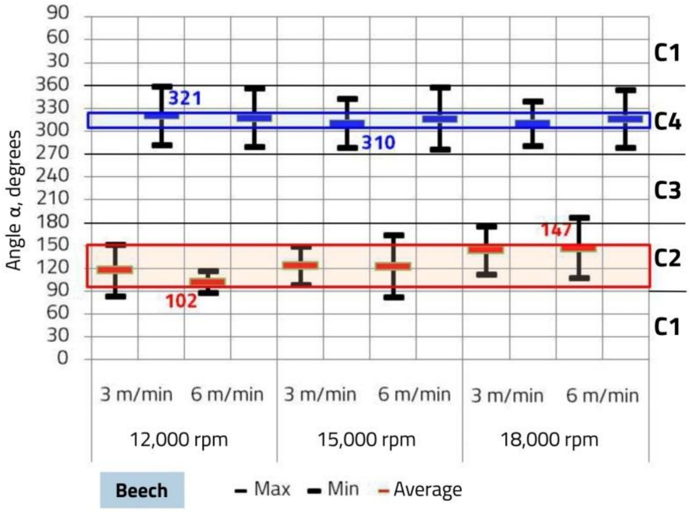

a



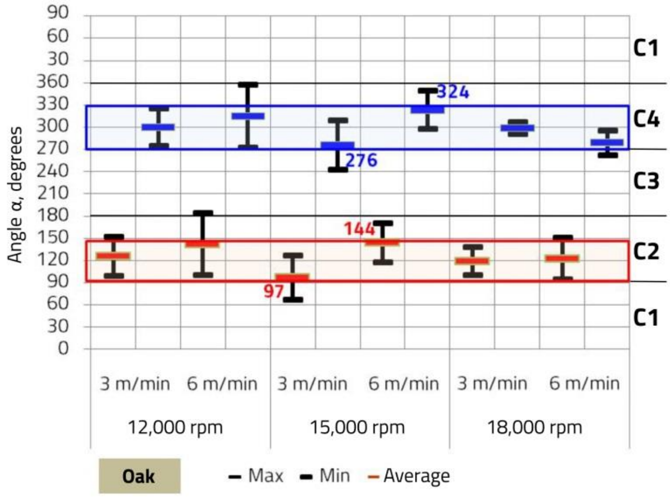

b




c




d




e

Fig 4.16. Graphic representation of the limits and average values of central angles for which defective surfaces were observed for the following wood species: a - spruce; b - larch; c - maple; d - beech; e - oak.

The graphical representation in Fig. 4.16 shows the distribution of areas where rough and raised fibers are observed, correlated with the limits and average values of the central angles within the circular model.

#### *4.4.2. Study on the Quality of the Machined Surface in Straight-Line Milling*

A total of 42 samples were available for measurement from each tested wood species, namely spruce, larch, maple, beech, and oak.

Roughness parameter measurements could not be performed on the spruce samples due to the wood breaking on significant portions of the sample edges.

The milling angles relative to the direction of the wood fibers were 0°, 15°, 30°, 45°, 60°, 75°, and 90°. The samples were cut out from panels (Fig. 4.17).

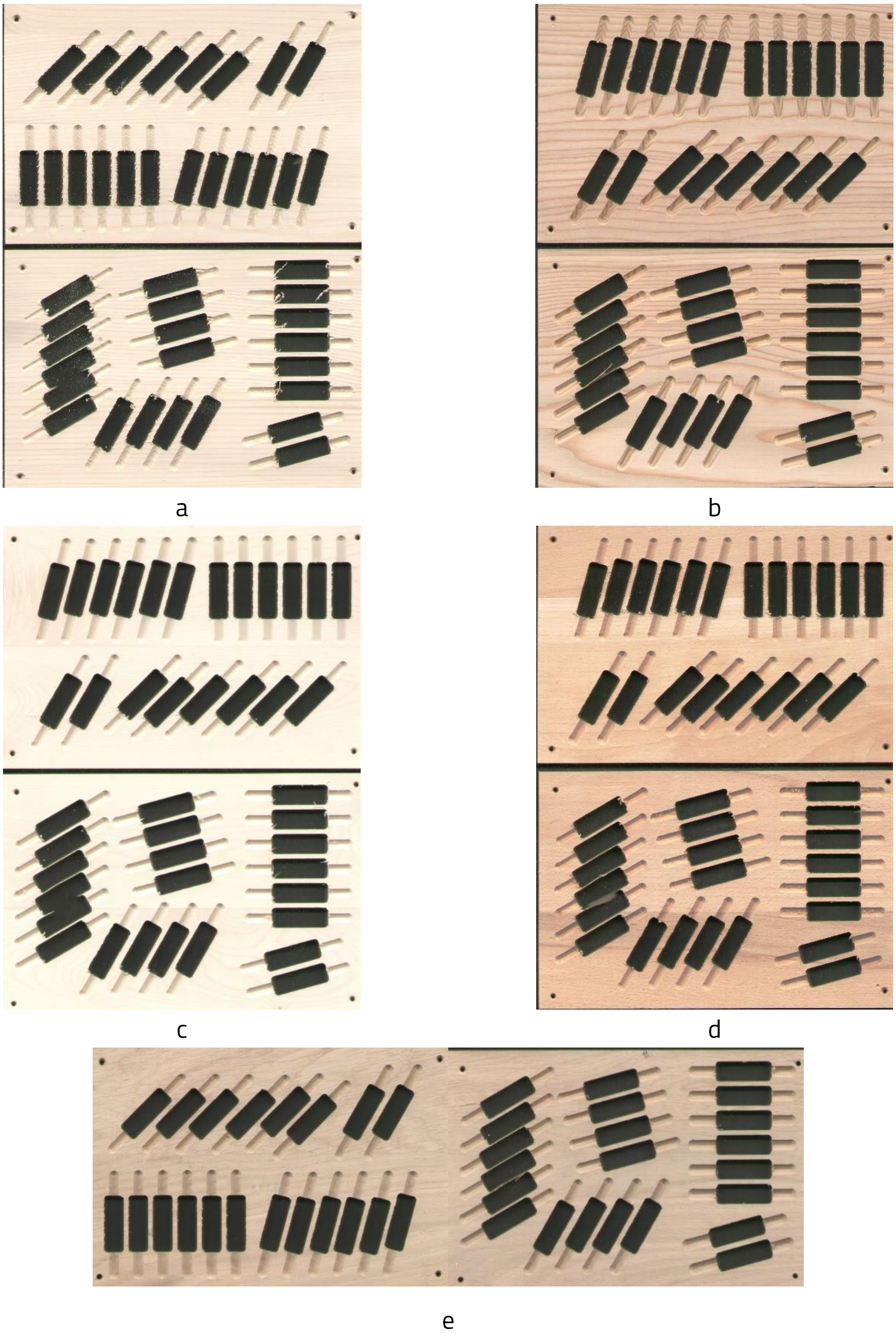
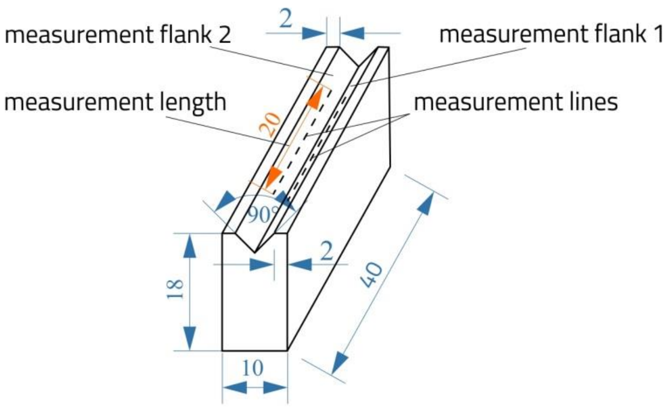



Fig 4.17. The panels from which the samples for roughness measurement were cut: a - spruce; b - larch; c - maple; d - beech; e - oak.




a b

Fig 4.18. Surface quality evaluation: a - sample measurements setup; b - the device for measuring perpendicular roughness on the flank.

The surface quality of the samples (Fig. 4.18) was evaluated using the MarSurf XT20 profilometer. A total of 6 measurements were performed for each milling combination. The following roughness parameters were used to assess the quality of the CNC-milled surfaces: Ra (arithmetic mean deviation of the roughness profile), Rv (maximum depth of the roughness profile), Rsk (skewness of the profile - the asymmetry of the probability density function about the mean line), Wa (arithmetic mean deviation of the waviness profile) according to ISO 4287 (2009), and Rk (core roughness profile), Rpk (reduced peak height of the roughness profile), Rvk (reduced valley depth of the roughness profile) according to ISO 13565-2 (1998).

As shown in Fig. 4.19, the results of the Ra roughness parameter (arithmetic mean deviation of the profile) indicate the highest values for larch wood (Fig. 4.19.a).

Oak wood also exhibited high values of this roughness parameter (Fig. 4.19.d).

These results align with the findings of another study (Sütçü and Karagöz, 2013) which showed that the inevitable effect of the heterogeneous structure of wood on surface quality varies substantially between measurements, as observed in the standard deviation representation for larch and oak in Fig. 4.19.a and 4.19.d.

It can be observed that for anatomically homogeneous species, such as (Fig. 4.19.b) and (Fig. 4.19.c), the differences in Ra values for the two feed speeds are small.

For beech wood, a feed speed of 3 m/min appears to be more advantageous in terms of surface quality.

The thesis also presents the results for the roughness parameters Rk, Rv, Rvk, Rpk, Rsk, and surface waviness expressed by Wa for the four wood species considered in this study.

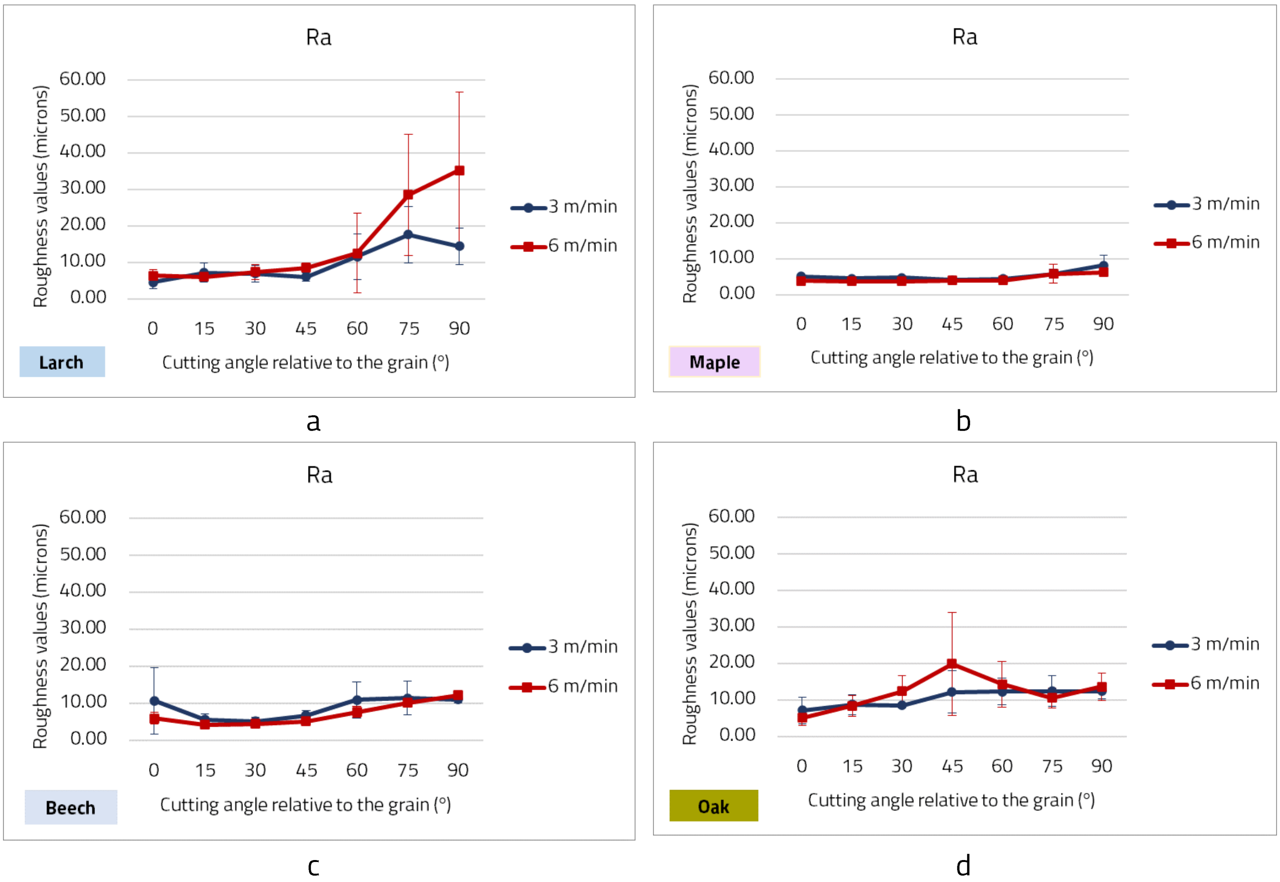



Fig 4.19. The average values of the parameter Ra, for CNC processing with two feed speeds and seven cutting angles relative to the fiber direction, evaluated for: a - larch; b - maple; c - beech; d - oak.

## 4.5. Research on the Possibility of Applying the Combined Method of Milling and Coloring

Within this research, methods of coloring and finishing were investigated in order to highlight the original ornamentation, taken from the textile heritage, in the decoration of finished furniture. Two coloring methods were used.

### *4.5.1. Coloring the Base Surface*

For coloring the surface, a walnut-colored coloring solution was used. Before application, the wood surface was sanded, and after drying, the pattern was processed by CNC milling using the *Engrave* method (Fig. 4.20.a) and the *V-Carve* method (Fig. 4.20.c), followed by the application of a layer of lacquer (Fig. 4.20.b and d).

a b c d

Fig. 4.20. Model 33 milled on a colored surface: a - CNC processing using the Engrave method; b - lacquering; c - CNC processing using the V-Carve method; d - lacquering.

The application of the *V-Carve* method is aesthetically advantageous, and the contrast between the ornament and the wooden support makes the milled pattern more visible.

### *4.5.2. Coloring the Ornament*

The coloring of the ornament, applied after CNC milling of the ornament using the two methods Engrave and V-Carve, was done according to the block scheme presented in Fig. 4.21, for the five wood species.

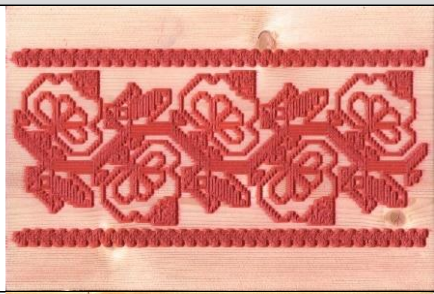
CNC miling (*Engrave* and *V-Carve*)
↓
Applying a water-based coloring solution
↓
Drying
↓
Sanding
↓
Applying primer
↓
Drying
↓
Sanding
↓
Applying lacquer
↓
Drying

Fig. 4.21. Block scheme for CNC milling technology, ornament coloring, and finishing.

The coloring variant of the ornament involved a study on the thickness of the sanded layer of wood from the base support to remove the applied color of the ornament.

The measurement of the final thickness was performed after both sanding operations on the panel. The results for spruce and oak are presented in Table 4.2.

Table 4.2. Results obtained for milling and coloring the ornament, followed by lacquering

| Species | Method | Operation | Image | Thickness, in mm | Thickness loss*, in mm |
|---|---|---|---|---|---|
| Spruce | *Engrave* | Lacquering |  | 17,89 | |
| Spruce | *V-Carve* | Lacquering |  | 16,91 | 0,98 |
| Oak | *Engrave* | Lacquering |  | 19,76 | |
| Oak | *V-Carve* | Lacquering |  | 18,78 | 0,98 |

* Average Calculated Values for the 6 Measurement Points.

The results presented in Table 4.2 illustrate that the *V-Carve* milling method applied to milling the ornament, followed by coloring the pattern and sanding to remove the color from the wood's base surface, is flawed in the case of spruce and oak wood species. The sanded thickness of approximately 1 mm for both sides, averaging 0.5 mm for each panel side, can remove portions of the ornament where the milling has a depth of 1 mm, especially if the panel is not perfectly flat.

# CHAPTER 5. EXPERIMENTAL RESEARCH ON THE POSSIBILITIES OF TRANSFERRING TRADITIONAL MOTIFS ON THE SURFACE OF FURNITURE THROUGH LASER ENGRAVING

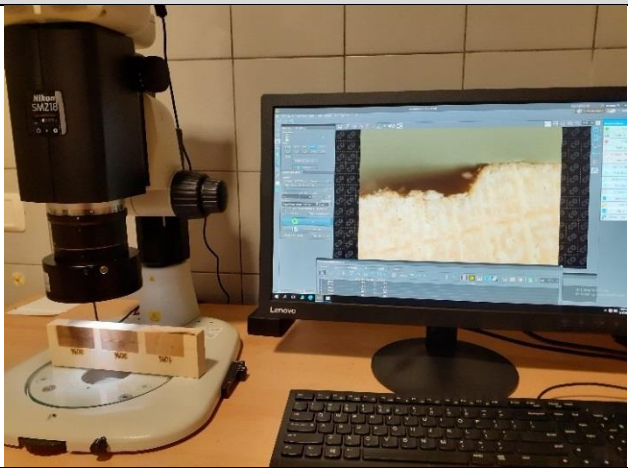
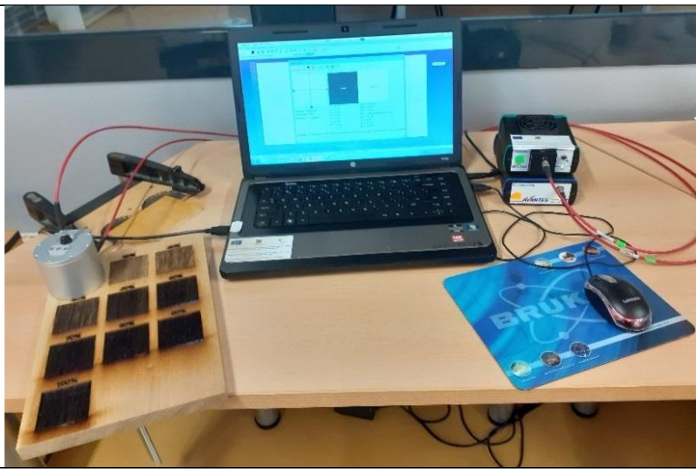
## 5.1. Equipment Used in the Research

The equipment used for this chapter of the doctoral thesis is part of the equipment available at the C14 Research Center at ICDT and is presented in Table 5.1.

Table 5.1. Equipment used in laser processing research

| Operation | Equipment | Manufacturer | Software |
|---|---|---|---|
| Gravare cu laser | OmniBEAM 150 Laser Machining Tool (LMT), equipped with nitrogen as the assist gas | COHERENT, INC., Santa Clara, California, USA | The LaserLinkTM CAM software was utilized to import files and set the working parameters, while the BEAM HMI was employed to control the cutting process |


| | | | |
|---|---|---|---|
| Microscopic investigation | NIKON SMZ 18 stereo microscope, with a magnification ratio of 18:1 and a magnification range between 22.5 x and 405 x. Magnifications used in the research: 22.5 x, 120 x. | Nikon Instruments, Melville, USA | NIS-Elements Imaging, used for image capture, measurements, and analysis |

| Operation | Equipment | Manufacturer | Software |
|---|---|---|---|
| |  | | |
| Color measurement | AvaSpec-2048 USB2 spectrometer, along with the AvaLight Hal light source and the integrated AVA sphere interconnected via optical fibers | AVANTES, Apeldoorn, Olanda | AvaSoft 7.7.2 Full |
| |  | | |
| Chemical investigation using FTIR | ALPHA Spectrometer, equipped with a Total Reflectance Accessory (ATR) unit | Bruker Ettlingen, Germania | OPUS version 7.2 |
| |  | | |

### 5.2. Study on Color Modification through Laser Engraving

For this experimental research, panels measuring 300 mm x 200 mm x 19 mm made of maple, beech, spruce, larch, and oak were laser-engraved. A total of 10 squares measuring 50 mm x 50 mm were engraved for each species and on each panel, using power levels ranging from 10% to 100% of the maximum power of the equipment, which is 150 W (Fig. 5.1).

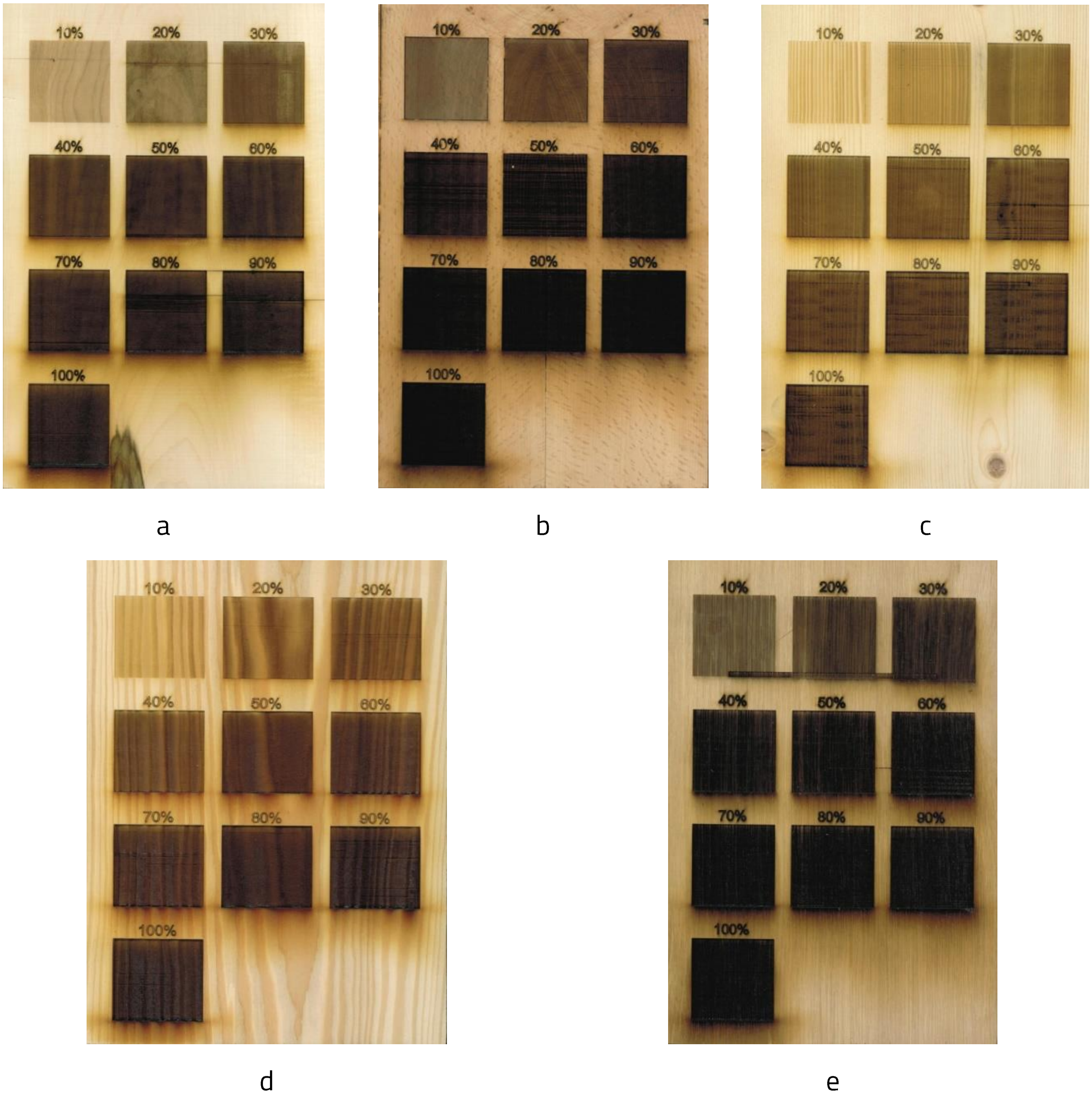



Fig. 5.1. Laser engraving with different power levels on the surface of wood: a - maple; b - beech; c - spruce; d - larch; e - oak

Color measurements were conducted using the AVANTES 2012 spectrometer. The color space utilized was CIELab, a three-dimensional colorimetric system established by the International Commission on Illumination (CIE) in 1976 (Fig. 5.2).

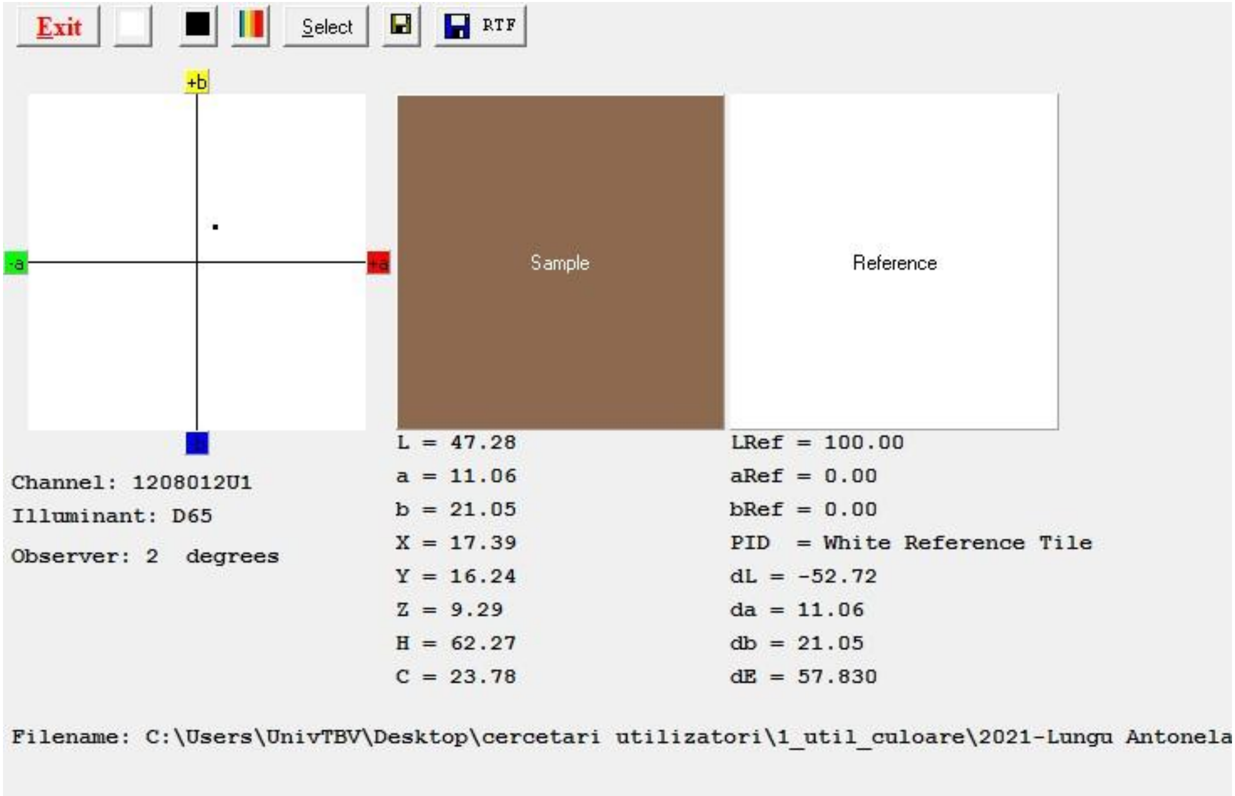



Fig. 5.2. CIELab color space.

For each measured point, values for *L*, a, and *b* were recorded. *L* represents the lightness ranging from 0 (black) to 100 (white), the *a* axis determines the red (positive) and green (negative) chromatic component, while the *b* axis specifies the yellow (positive) and blue (negative) chromatic component.

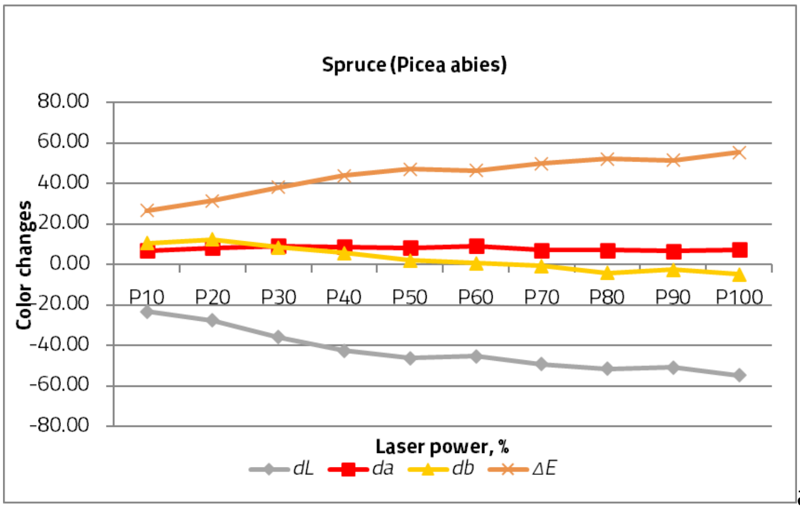
To evaluate the difference between two colors, the total color difference *ΔE* was calculated to express the distance between two points in the CIELab system, according to Equation (5.1):

$$\Delta E = (dL^2 + da^2 + db^2)^{1/2} \quad (5.1)$$

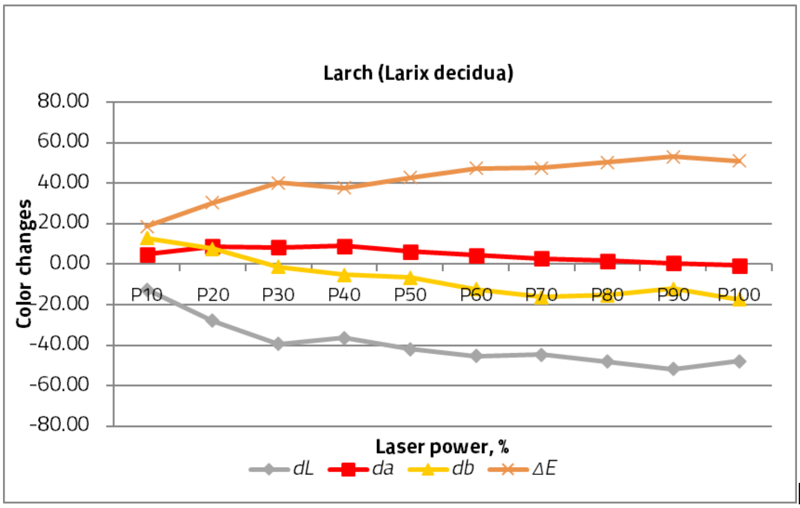
where *dL* is the difference in lightness, *da* is the difference in the red-green index, *db* is the difference in the yellow-blue index, and *ΔE* is the total color difference calculated (Kubovský and Kacik, 2013).

*dL*, *da*, and *db* represent the differences between the average values measured after wood engraving and the average values for the control sample.

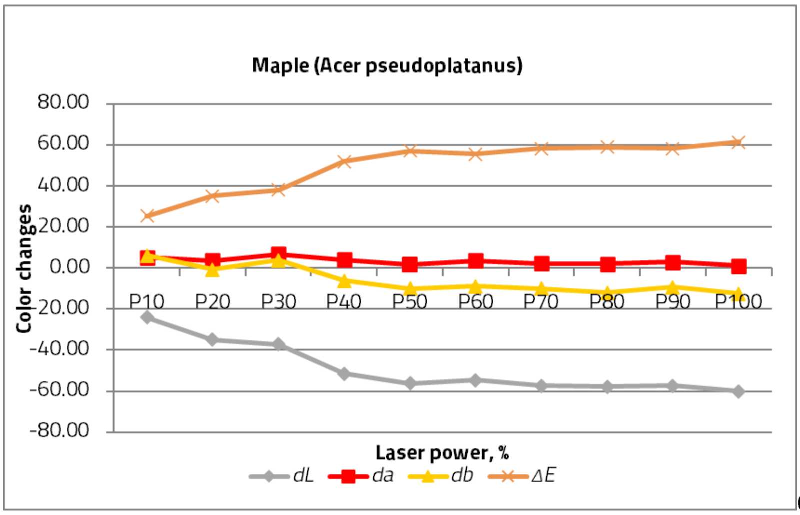
The color changes for the analyzed species, based on laser power, are presented graphically in Figure 5.3. It can be observed that the shape of the *ΔE* curves is a mirror image of the lightness differences dL (the differences da and db only serve to change the negativity of the final result).


Spruce (Picea abies)
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
Color changes
P10
P20
P30
P40
P50
P60
P70
P80
P90
P100
Laser power, %
dL
da
db
ΔE

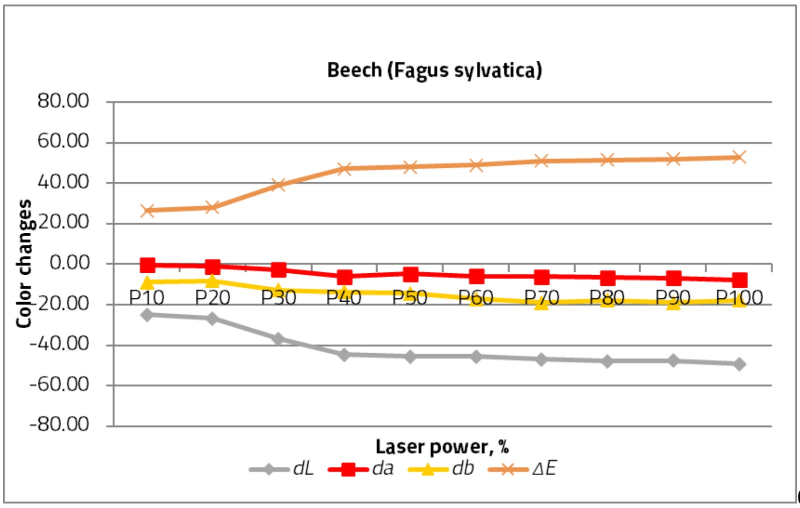
a.


Larch (Larix decidua)
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
Color changes
P10
P20
P30
P40
P50
P60
P70
P80
P90
P100
Laser power, %
dL
da
db
ΔE

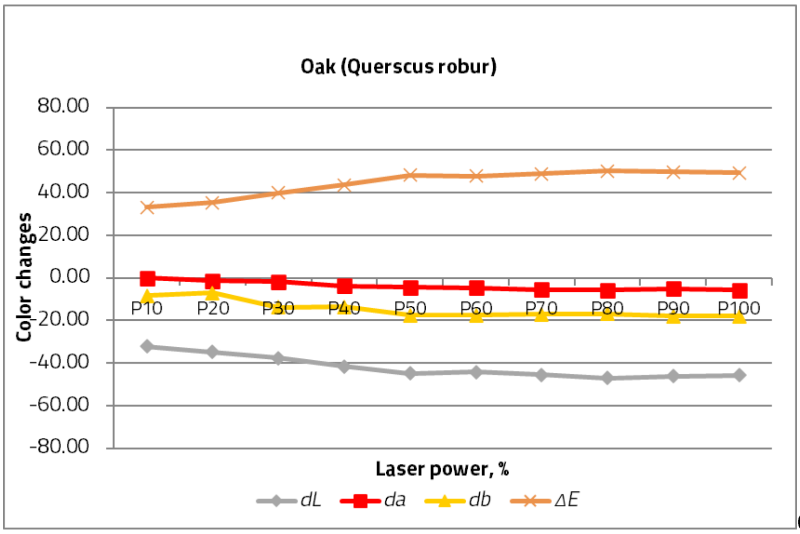
b.


Maple (Acer pseudoplatanus)
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
Color changes
P10
P20
P30
P40
P50
P60
P70
P80
P90
P100
Laser power, %
dL
da
db
ΔE

c.



d.



e.

Fig. 5.3. Color changes after laser engraving on the surface for the five investigated wood species.

Based on the laser power, the engraving penetrated the wood to different depths, which were determined using the Nikon SMZ 18 stereo microscope with magnifications of 30 x and 60 x.

The images obtained with the stereo microscope for measuring the engraving depths are presented in Fig. 5.4, Fig. 5.5, Fig. 5.6, Fig. 5.7, and Fig. 5.8.

Analyzing the laser-engraved wood surface after the complete processing of the squares, it was observed that brown-colored stains remained on the base surface of the panel in the vicinity of the irradiated area. These stains need to be removed before applying the finishing layer.

To experimentally determine the thickness of the removed layer through sanding, the panel thickness was first measured at three points. Then, sanding was performed using abrasive material with a grit size of 100 over the entire surface until all burns on the wood surface were completely removed. The thicknesses obtained after sanding were measured, and the differences compared to the initial thicknesses were calculated.

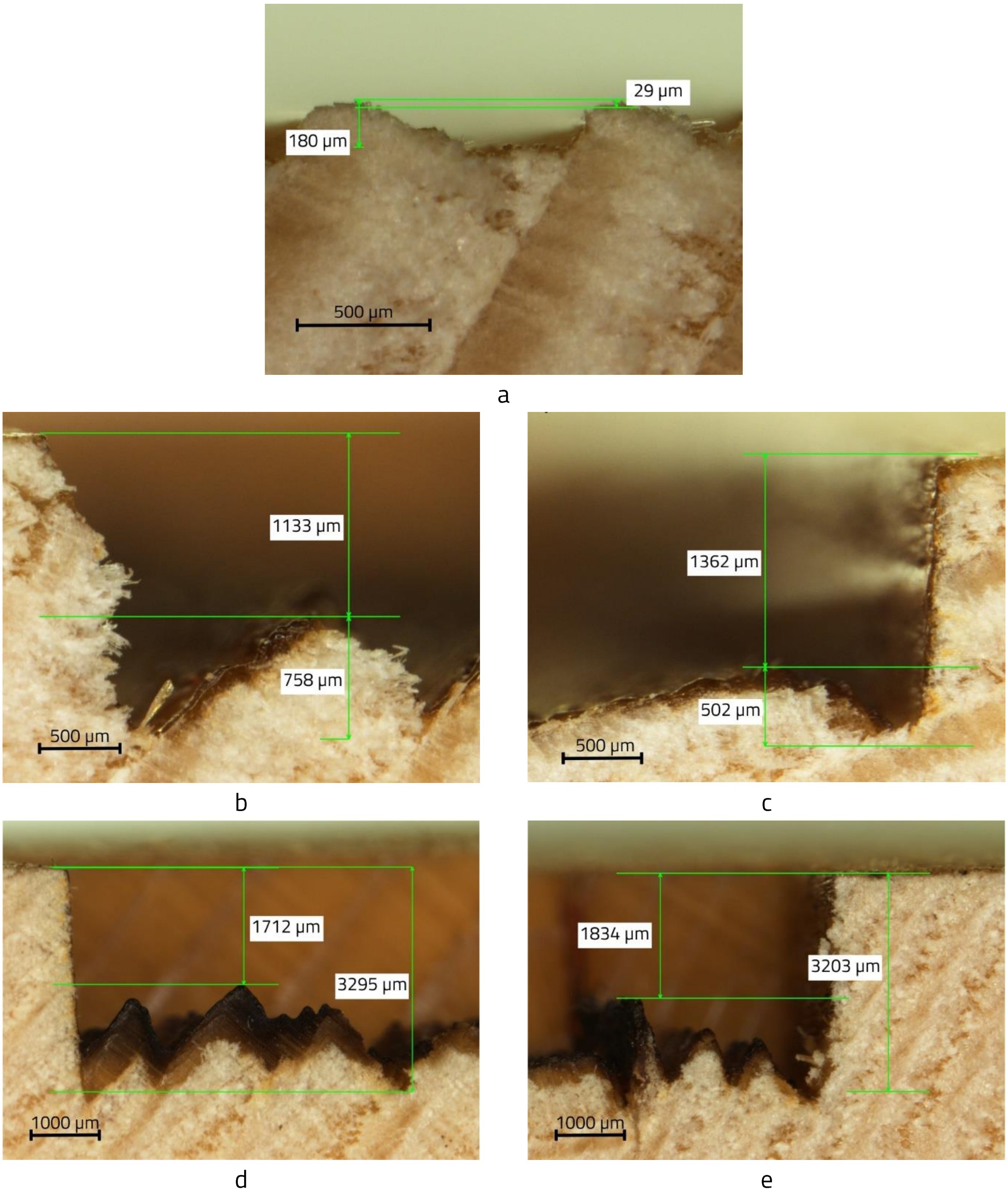



Fig. 5.4. Laser engraving depth of spruce wood measured for wood surfaces engraved with laser power of: a - 10% (90 ×); b, c - 50% (60 ×); d, e - 100% (30 ×), of the maximum power of the laser beam.

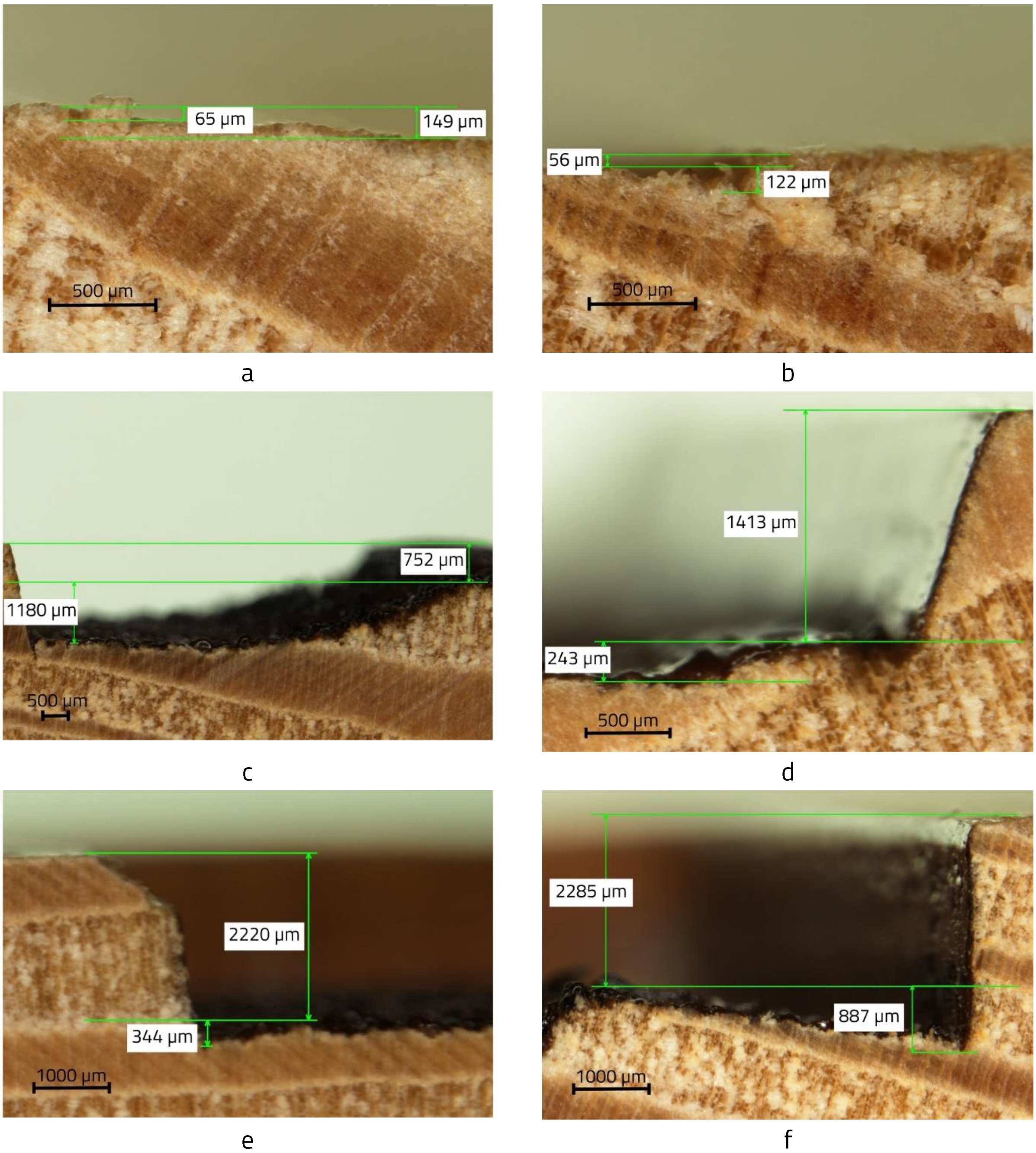



Fig. 5.5. Laser engraving depth of larch wood measured for wood surfaces engraved with laser power of: a, b - 10% (90×); c - 50% (22.5×); d - 50% (60×); e, f - 100% (30×), of the maximum power of the laser beam.

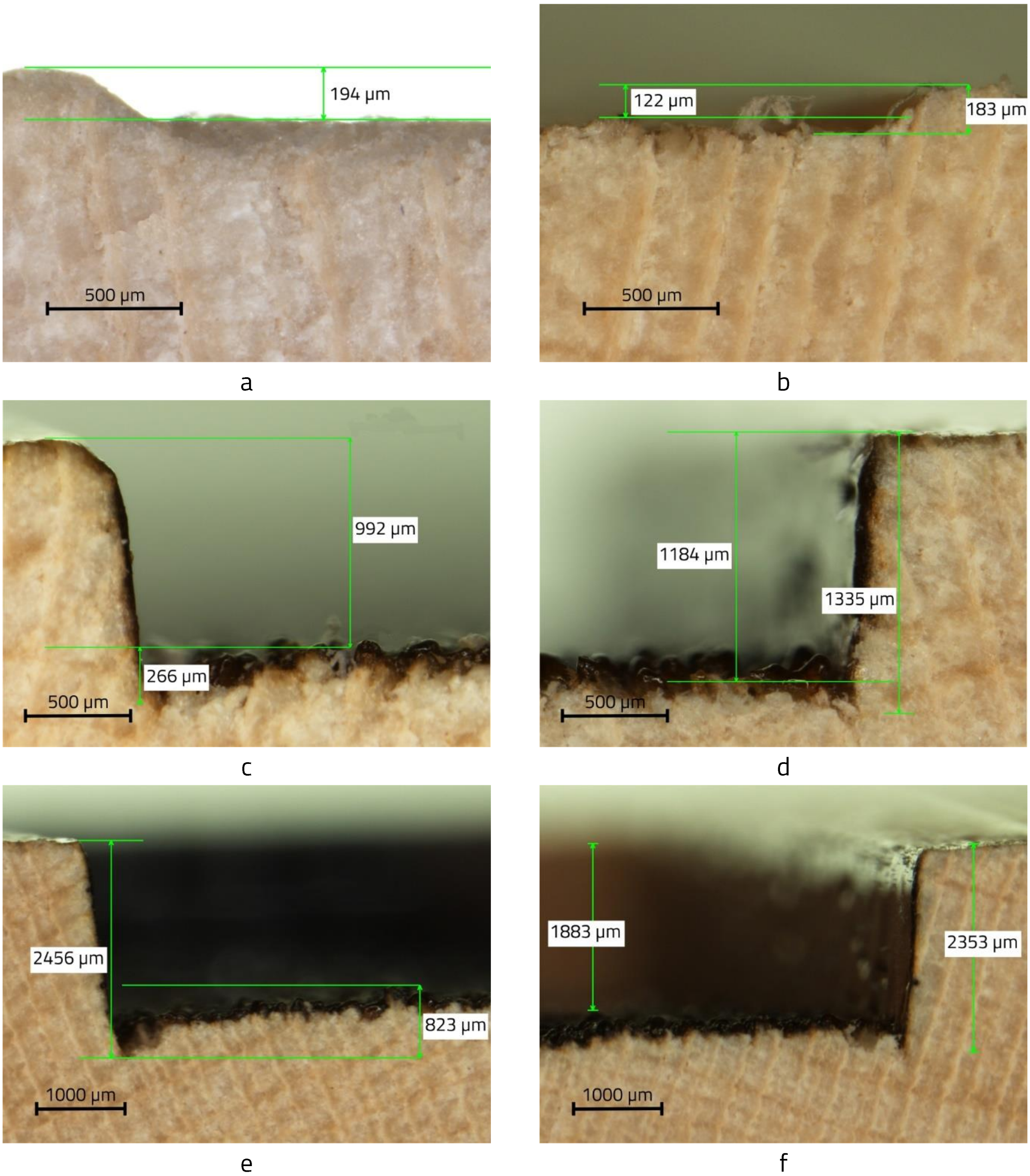
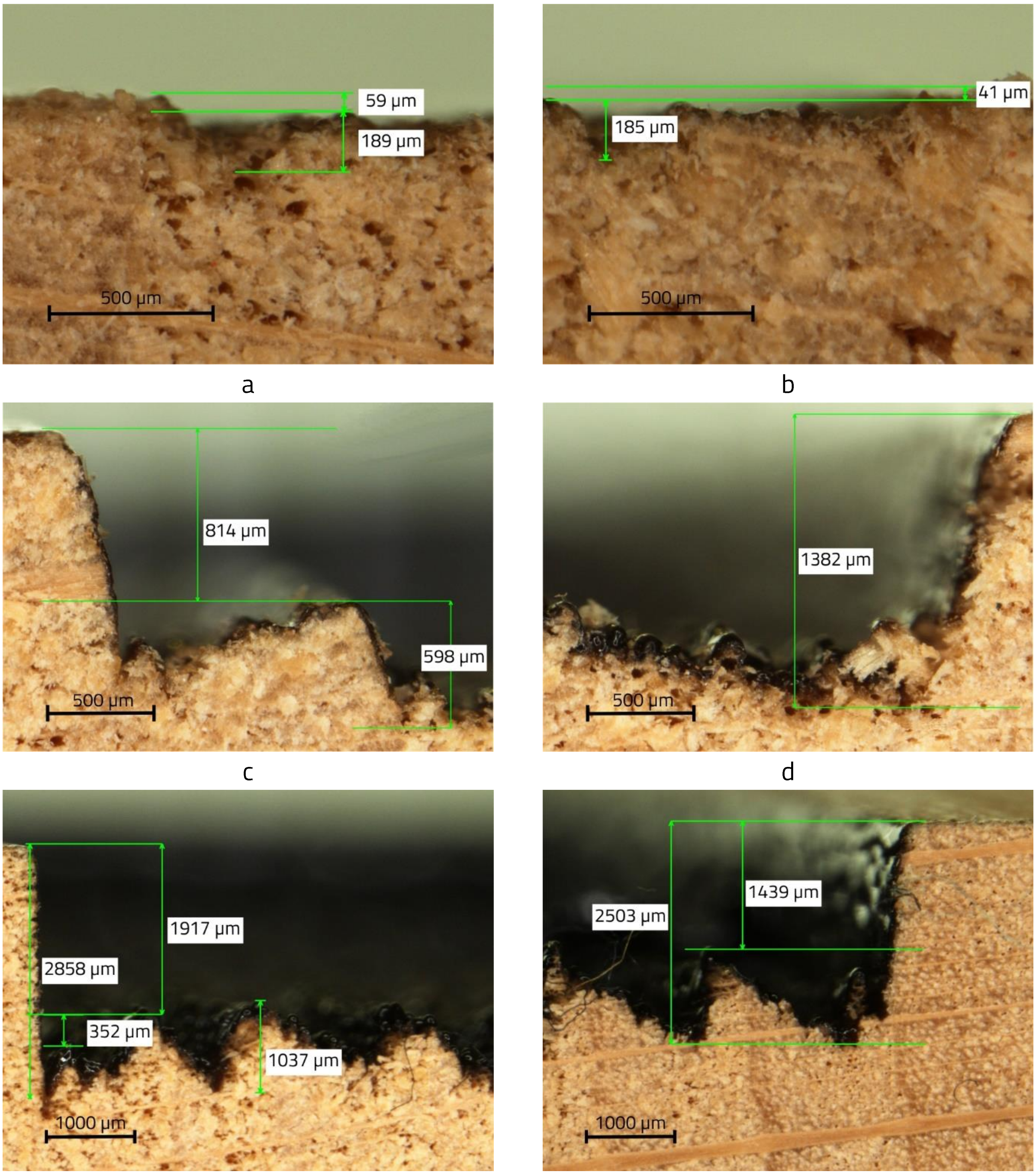



Fig. 5.6. Laser engraving depth of maple wood measured for wood surfaces engraved with laser power of: a, b - 10% (90 ×); c, d - 50% (90 ×); e, f - 100% (30 ×), of the maximum power of the laser beam.




e f

Fig. 5.7. Laser engraving depth of beech wood measured for wood surfaces engraved with laser power of: a, b - 10% (90 ×); c, d - 50% (90 ×); e, f - 100% (30 ×), of the maximum power of the laser beam.

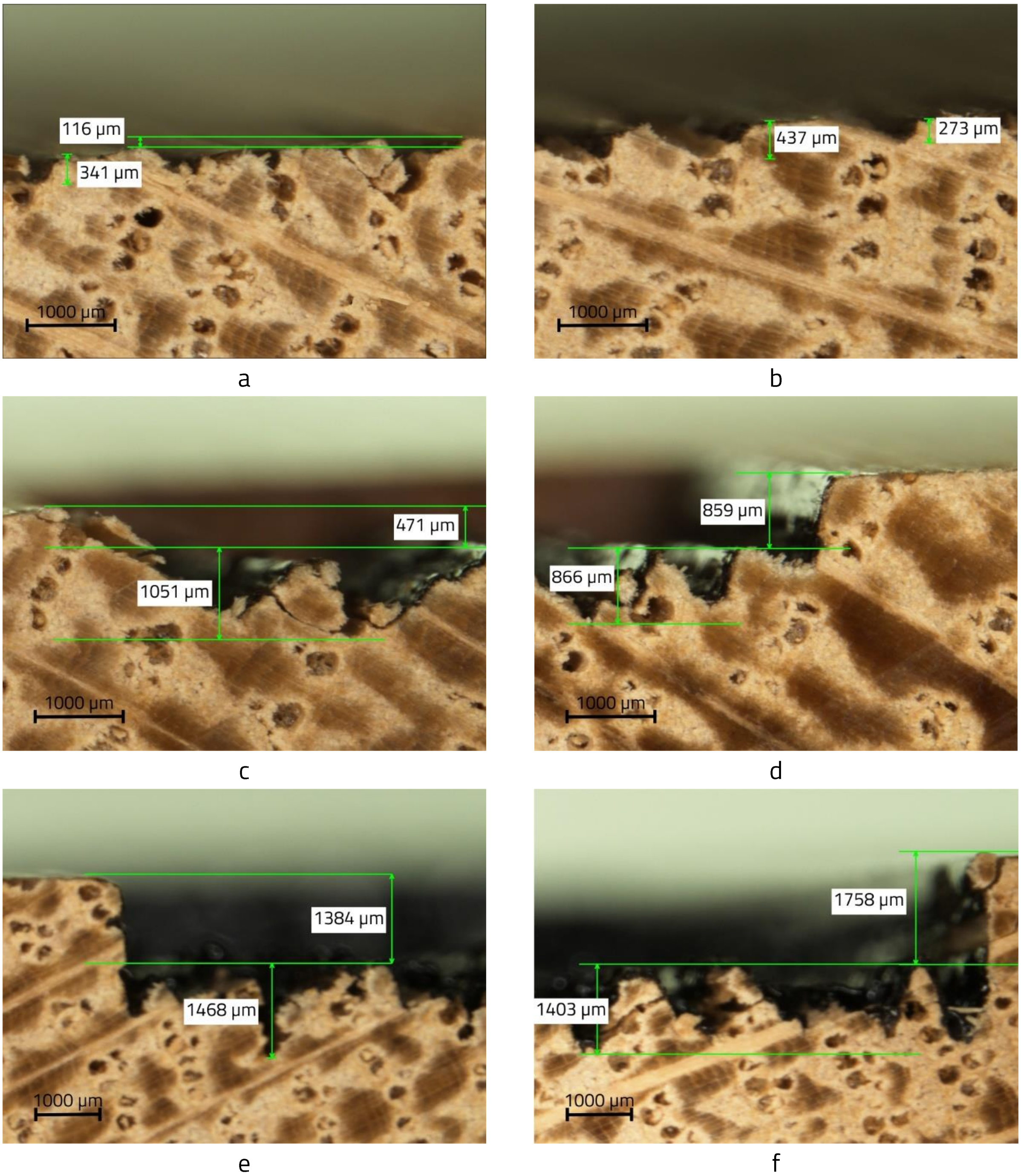


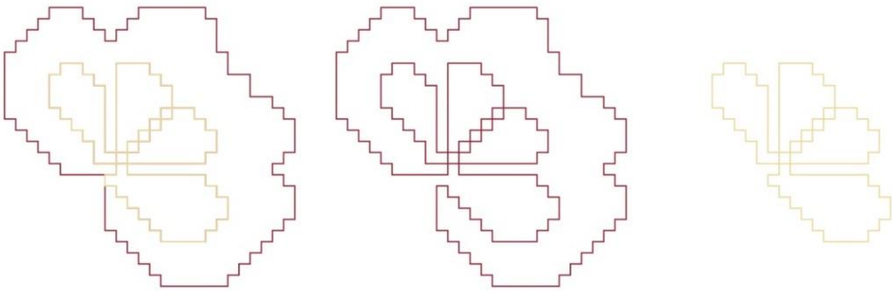

Fig. 5.8. Laser engraving depth of oak wood measured for wood surfaces engraved with laser power of: a, b - 10% (30 ×); c, d - 50% (30 ×); e, f - 100% (22.5 ×), of the maximum power of the laser beam.

The thickness of the wood layer removed by sanding is greater for spruce, larch, and oak species. These values exceed the depth of wood burning achieved through engraving with 10% power for all three species, and even the depth of wood burning achieved through engraving with 20% power for spruce and larch. For these species, choosing these power levels is not recommended for lighter colors of the engraved decorative pattern.

## 5.3. Experimental Research on Applying Color Study Results

An important step in accurately reproducing a color image through laser engraving is to preserve the brightness difference between the original colors and the laser-engraved ones. For this research, two light-colored species, namely spruce and maple, were chosen.

For the study, model 33 from the database in Chapter 3 was selected. The original pattern is bicolor, and therefore, to be processed separately with different laser beam powers, the two decomposed parts of the pattern in Fig. 5.9.a were saved as two vector files, one for each color, as seen in Fig. 5.9.b and c.



a b c

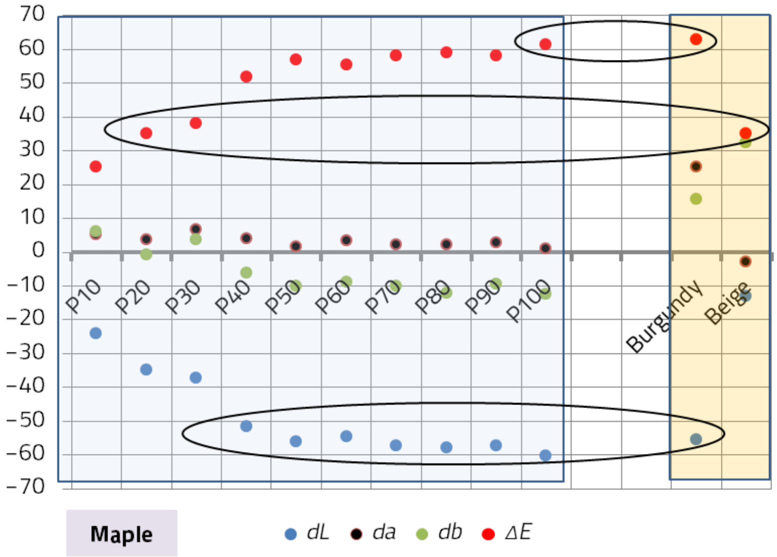
Fig. 5.9. The drawing of the selected detail: a - complete outline; b - burgundy outline; c - yellow outline (Lungu *et al.*, 2022b).

To measure the color difference (ΔE) between the original colors of the pattern taken from the textile heritage, the outline of the design in vector format was filled with colors selected from model 33 using the graphic program *CorelDraw X7* (Fig. 5.10.a).

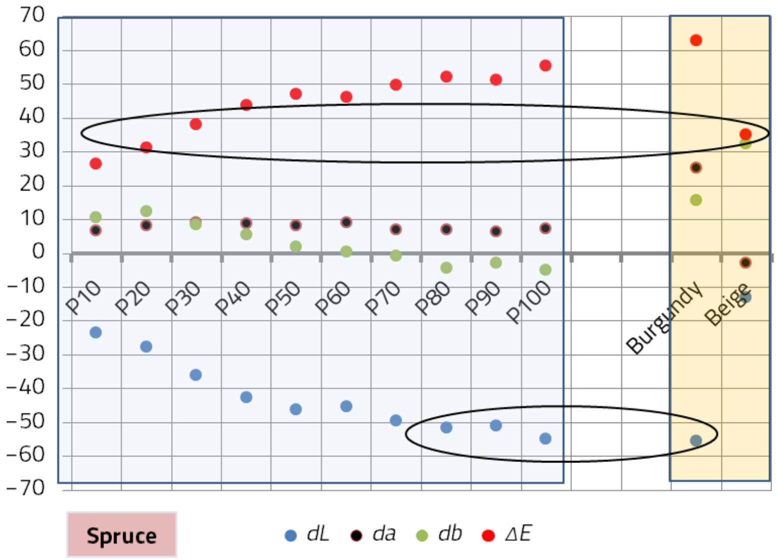
a b c

Fig. 5.10. Digital combination for the detail of the traditional pattern: a - complete drawing; b - selected color for burgundy, RGB (red, green, blue) 152, 33, 49; c - selected color for beige, RGB 240, 214, 153 (Lungu *et al.*, 2022b).

A graphical representation of the results for brightness differences (*dL*), the red-green chromatic component (*da*), the yellow-blue chromatic component (*db*), as well as the total color difference *(ΔE)* between the laser-processed wood surfaces and the control wood, i.e., the original color of the pattern and the control cardboard, is presented in Fig. 5.11.




a




b

Fig. 5.11. Comparison of colors based on laser beam power using three-dimensional colorimetric analysis CIELab: a - maple wood; b - spruce wood.

To achieve a contrast between engraved colors that closely resembles the contrast of the original colors of the pattern to be reproduced, the color contrast was assimilated with the difference between the respective *ΔE* values of the colors, each calculated in relation to the corresponding control. In the case of laser-engraved surfaces, the assimilated contrast differences were calculated considering the comparison values as the colors resulting from engraving with laser beam powers of 10%, 20%, and 30% of the maximum laser power. An illustration of these calculated values is presented in the diagram in Fig. 5.12.

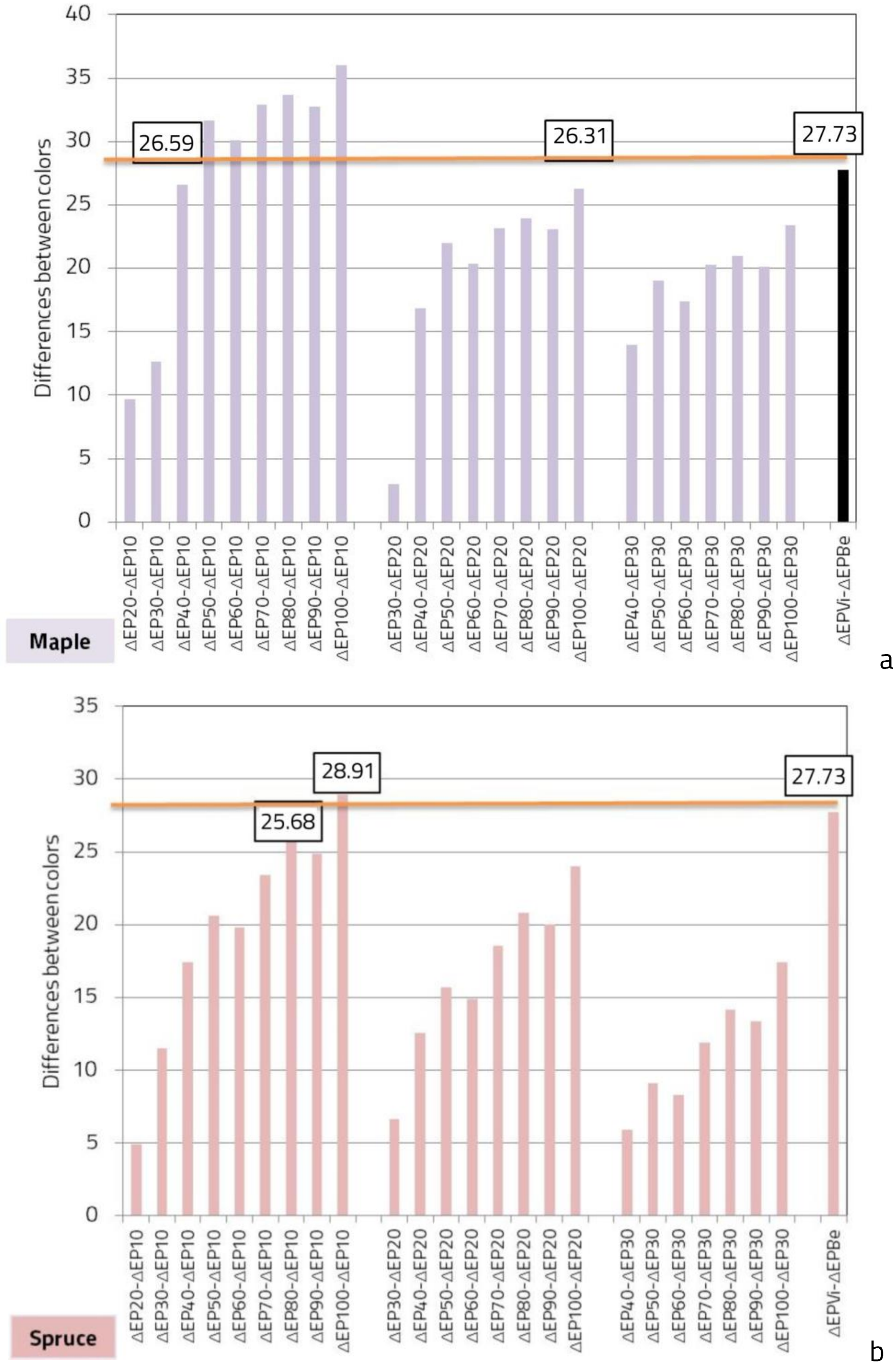



Fig. 5.12. Comparison of assimilated contrast differences in ΔE values for the original colors: burgundy (Vi) and beige (Be), and the corresponding shades of brown for laser-engraved surfaces: a - maple wood; b - spruce wood.

In conclusion, if approximate *ΔE* values are obtained for both the original colors of the pattern and the laser-engraved wood surface, similar contrasts are expected between the original pattern and the laser-engraved pattern.

## 5.4. FTIR Investigations (Fourier Transformed Infra-Red Spectroscopy)

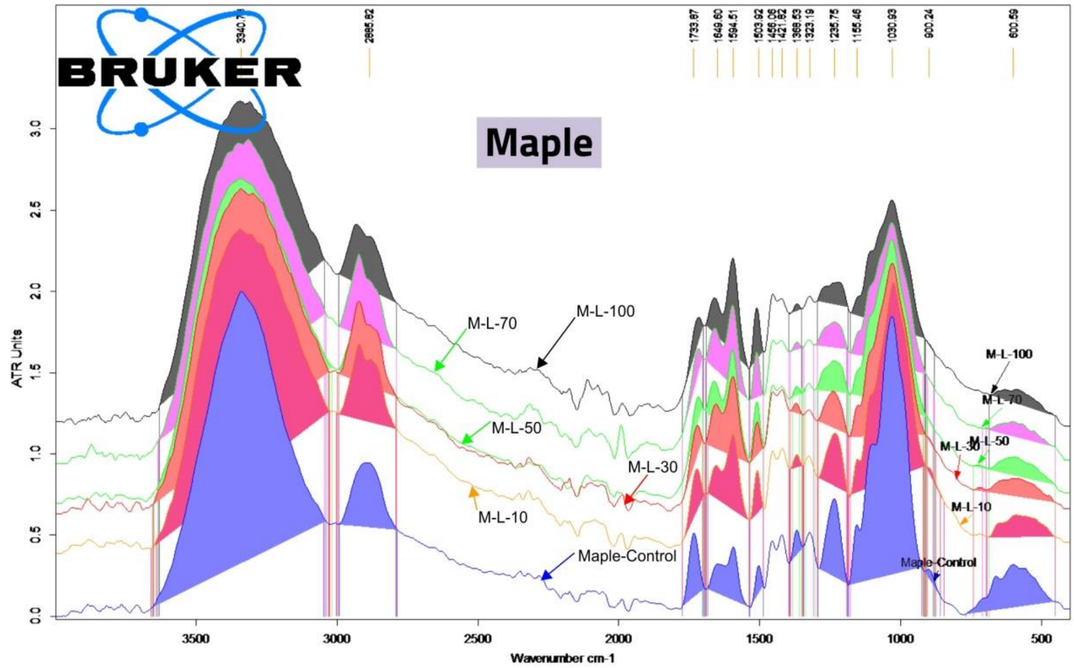
The changes in the chemical composition of wood under the influence of thermal effects associated with laser surface processing were highlighted and evaluated using Fourier Transformed Infra-Red spectroscopy (FTIR). FTIR spectra were recorded using an ALPHA Bruker spectrometer. Data from specialized literature and internal databases created through investigations and research projects within C14/ICDT were used to identify absorption bands.

For spruce and maple species, FTIR samples were collected from the laser engraving zones with beam powers of 10%, 30%, 50%, 70%, and 100% of the maximum power. For a more accurate assessment of these changes, a semi-quantitative analysis based on the integration of relevant absorption peak areas was performed using dedicated functions of the OPUS 7.2 software (Fig 5.13).

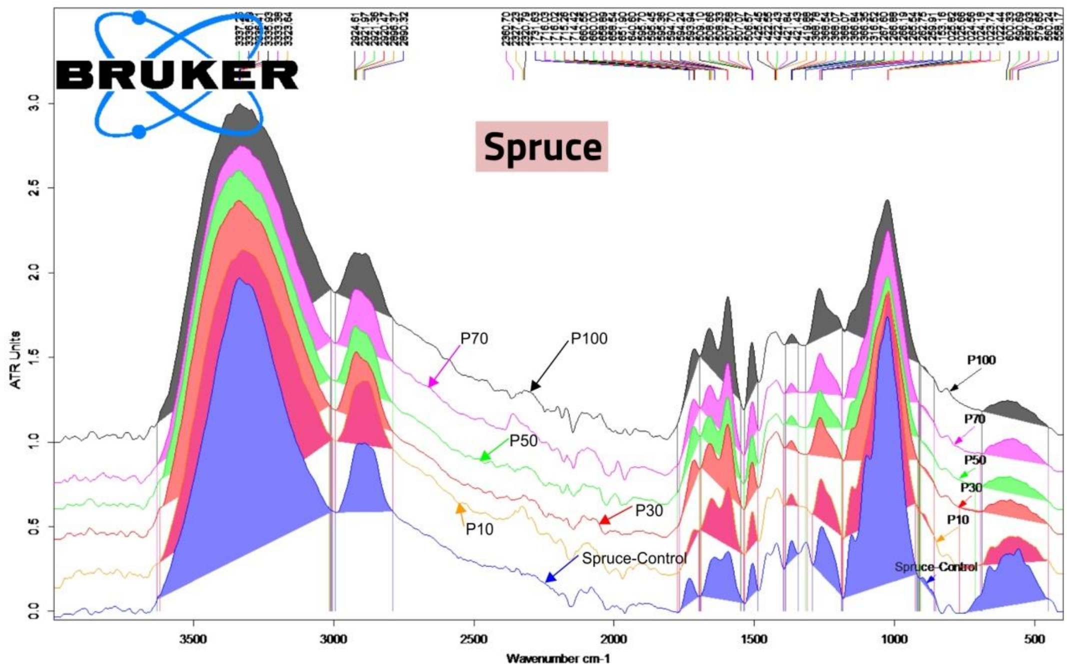
Some modifications in the surface chemistry of wood are illustrated by the variation diagrams of the relative FTIR ratios presented in Fig. 5.14. For maple (Fig. 5.14.a), the general trend is that higher laser beam powers lead to a more pronounced decrease in the relative area, indicating the degradation of carbohydrates. Additionally, higher laser beam powers accelerate the reciprocal reaction of functional groups, resulting in further condensation of lignin, as concluded by (Kubovsky and Kacik, 2014) and (Li *et al.* , 2018).

For spruce (Fig. 5.14.b), the evolution of these ratios is different, although the general trend of subunitary ratios for carbohydrates and superunitary ratios for lignin is maintained. The non-uniform evolution of relative areas with increasing laser beam power may be related to the non-uniformity of the wood material (e.g., different structural characteristics of the wood samples, such as earlywood/latewood, presence of resin channels), without excluding experimental errors in the integration of less evident absorption bands. The decrease in carbonyl groups (less numerous compared to maple) may be followed by thermo-oxidation processes with the formation of new carbonyl groups. Such evolutions are typical for high-temperature wood treatment processes, as observed by (Kačíková *et al.*, 2008).

In summary, the FTIR analysis performed in the current research revealed significant chemical modifications in the wood structure caused by the thermal effect associated with laser engraving. These modifications primarily affected the polysaccharides, especially hemicelluloses, and to a lesser extent lignin. The analysis also identified the presence of lignin cleavage and condensation processes in thermally treated wood. The results are in line with other studies (Petutschnigg *et al.*, 2013), (Kubovsky and Kacik, 2009), (Timar *et al.*, 2016).

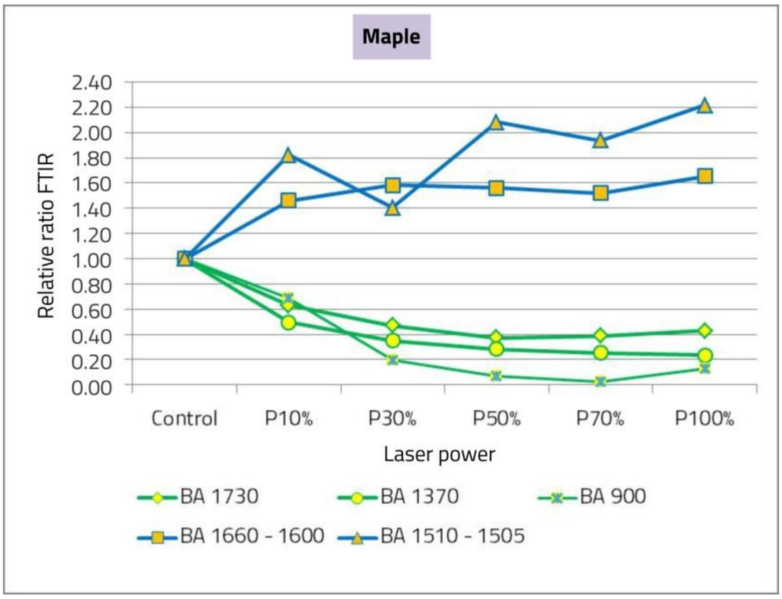



a

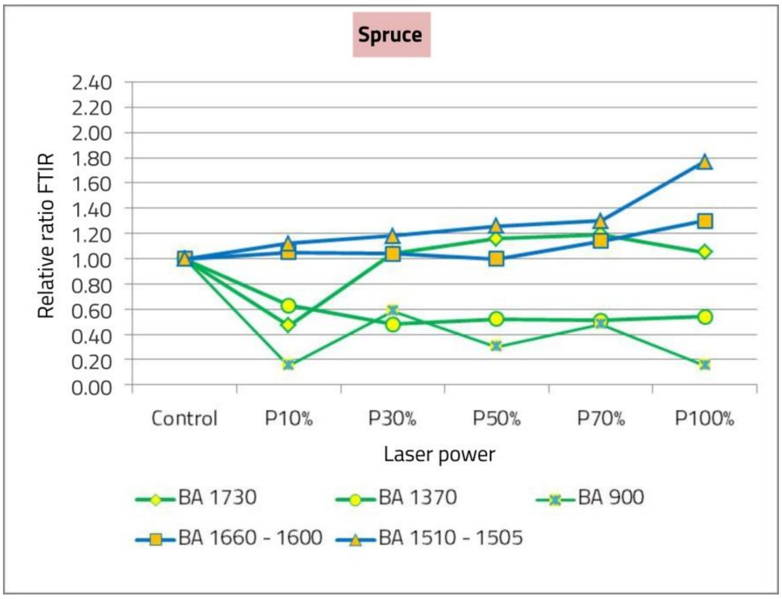



b

Fig. 5.13. Processing of spectra through integration for semi-quantitative evaluation of chemical modifications: a - maple wood for control (Maple-Control) and laser engraving (M-L-10, M-L-30, M-L-50, M-L-70, and M-L-100) with 10%, 30%, 50%, 70%, and 100% of the maximum laser beam power; b - spruce wood for control (Spruce-Control) and laser engraving (P10, P30, P50, P70, and P100) with 10%, 30%, 50%, 70%, and 100% of the maximum laser beam power.



a



b

Fig. 5.14. Variation of relative FTIR ratios for laser-engraved samples relative to control samples, based on laser beam power of 10%, 30%, 50%, 70%, and 100% of the maximum power of 150 W, for: a - maple wood; b - spruce wood.

## 5.5. Examples of Traditional Patterns Engraved on Maple Wood Surfaces

The four studied ornaments, including the ones applied with CNC milling methods, were engraved using laser beams after digitally drawing the patterns, decomposing the designs by colors, and exporting the files in *AutoCAD LT 2002*. The ornament processing on the wood surface was then carried out through engraving.

Models 64 and 65 (Fig. 5.16.a and Fig. 5.15.a) were executed through full or patterned embroidery, while models 33 and 8 were created using cross-stitching (Fig. 5.18.a and Fig. 5.19.a).

The three colors of model 64 were separated into three files, one for each color (Fig. 5.17.), and different laser beam parameters were configured for each file.

a b c

Fig. 5.15. Model 65: a - complete design; b - outline design; c - processed ornament.

a b c

Fig. 5.16. Model 64: a - complete design; b - outline design; c - processed ornament.

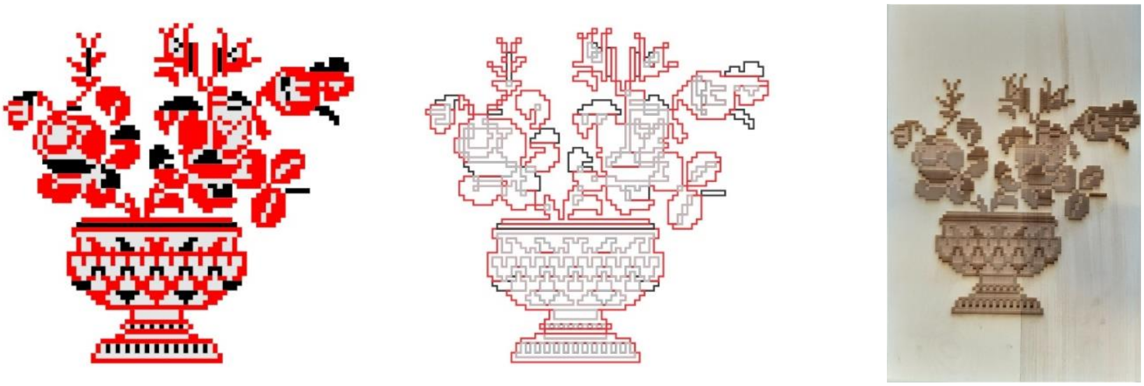
a b c

Fig. 5.17. Decomposition of model 64 into contours: a - light color; b - medium color; c - dark color.

Similarly, the same procedure was followed for Model 33, which consists of two colors (Fig. 5.18.b and c), and for Model 8, also composed of three colors (Fig. 5.19.a, b, and c), decomposed into the three colors as shown in Fig. 5.20.

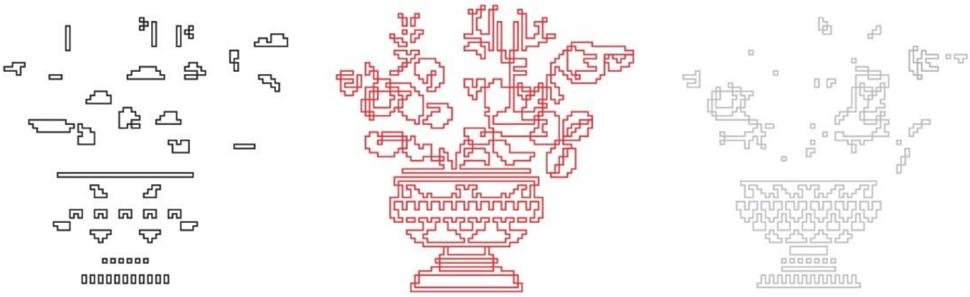
a b c d

Fig. 5.18. Model 33 with outlines: a - complete; b - burgundy; c - beige; d - processed ornament.



a b c

Fig. 5.19. Model 8: a - complete design; b - outline design; c - processed ornament.



a b c

Fig. 5.20. Decomposition of model 8 into outlines: a - black; b - red; c - white.

# CHAPTER 6. GENERAL CONCLUSIONS. ORIGINAL CONTRIBUTIONS. DISSEMINATION OF RESULTS. FUTURE RESEARCH DIRECTIONS

## 6.1. General Conclusions

- As digitization techniques and wood processing technologies have become increasingly advanced, they could enable the revitalization of furniture decoration techniques, providing opportunities for the promotion and preservation of cultural heritage elements.
- The research presented in the doctoral thesis proposes the transposition of motifs from Romanian textile heritage onto wooden surfaces for ornamentation, using digitization methods and advanced CAD-CAM-CAE design.
- Transforming traditional motifs into digital format using graphic software, importing them into CAD files, and simulating CNC milling using specialized software are actions that can provide an idea of the processed ornament's appearance based on the selected tool and method, processing time, and milling path. Image analysis software (*ImageJ*) provides data on the processed area and its percentage of the total area of the processed panel. These modern tools can anticipate the advantages and disadvantages of selecting processing parameters.
- The technique of creating the textile motif (embroidery or cross-stitch), the shape and type of contours (closed or open), influence the choice of milling transposition method.
- Aesthetically, models processed with 120° tip angle milling cutters appear overly intricate, so milling with a 90° angle cutter is recommended, especially for engraving.
- The *V-Carve* method can be applied to complex models with large surfaces bounded by closed contours. The drawing area inside the closed contour will be deeply carved. However, this method is not recommended for certain shapes of the model with contour discontinuities.
- In the *V-Carve* method, partial processing of the model occurs in areas where the processing depth is only 1 mm. Calibrating the panel before milling is mandatory.
- In the *Engrave* method, wear affects the cutting edge area more, while in the *V-Carve* method, wear on the tip is greater.
- The choice of milling method represents a compromise between appearance, surface quality, tool wear, and processing times.
- Experimental research on the surface quality of curved contours processed on CNC has shown that the optimal milling parameters for surfaces with minimal chip formation, raised fibers, and fiber tear-outs are as follows: for spruce, sycamore, and oak - a rotation speed of 18,000 rpm and a feed rate of 3 m/min, for larch - a rotation speed of 12,000 rpm and a feed rate of 3 m/min, and for beech - a rotation speed of 12,000 rpm and a feed rate of 6 m/min.

- The results of measuring roughness parameters Ra, Rk, Rv, Rvk, Rpk, Rsk, and Wa on samples milled at angles of 0°, 15°, 30°, 45°, 60°, 75°, and 90° relative to the fiber direction indicate the highest values for larch wood, especially when milled perpendicular to the fibers (90°) and at 75° with a feed rate of 6 m/min, followed by oak wood at milling angles of 30°, 45°, and 60°, with a maximum at 45° for a feed rate of 6 m/min. The lowest values were recorded for sycamore wood, with a slight increase at angles of 75° and 90°, regardless of the feed rate, followed by beech wood, with variations in roughness increase at angles of 45°, 60°, 75°, and 90°, as well as along the fiber direction.
- Coloring the wooden substrate followed by ornament milling is aesthetically advantageous, and the contrast between the ornament and the wooden substrate highlights the processed pattern. Coloring the ornament followed by full surface sanding is risky as sanding can remove some of the ornament details, especially in the case of *V-Carve* milling. Panel calibration is mandatory.
- For laser engraving, the digital model needs to be decomposed into its component colors, and the processing is done separately and successively. Light-colored wood species and complex traditional patterns are recommended for laser engraving.
- The correlation of colors from traditional textile patterns with those of the laser-engraved pattern on the wooden surface, depending on the laser beam power, can be done based on the total color difference ($\Delta E$).
- The depth of laser engraving in wood, determined at a microscopic level for all laser engraving powers and wood species, provides information on the allowable thickness of the wood layer that can be removed by sanding (if done mechanically) to eliminate stains/burn marks on the processed wood surface without affecting the low-powered engraved section of the pattern.
- FTIR investigations have revealed chemical changes in the laser-engraved wood structure, with carbohydrate compounds such as hemicelluloses and cellulose degrading under the influence of temperature. The FTIR spectra show an apparent increase in lignin content.
- The processing times for laser engraving ornaments are longer than when milling them on CNC, but laser-engraved ornaments gain in their aesthetic appearance.

## 6.2. Original Contributions

- An innovative solution to the problem of preserving, conserving, and transmitting the cultural heritage of the Țara Bârsei and its surroundings, as well as creating national identity in furniture design.
- An interdisciplinary approach from fields such as graphic design, computer-aided design, CAM-CAE software, the use of image analysis programs (*ImageJ*), milling and laser engraving

technologies, microscopic analysis and measurements, color analysis, qualitative surface analysis, and FTIR analysis.

- Transforming traditional motifs into digital format using graphic software and creating a database containing 100 traditional motifs from textile heritage.
- Using *VCarvePro 9.519* software for importing digitized files into CAD files and simulating CNC milling to select the processing method, tool, working parameters, and forecast processing times.
- Using ImageJ software to obtain the processed area and its percentage of the total area of the panel.
- Correlating the method of stitching the textile motif (embroidery or cross-stitch) with the method of wood surface processing through milling (*Engrave* or *V-Carve*).
- Selecting milling parameters by evaluating the aesthetic appearance obtained on different wooden surfaces, aiming for a faithful representation of the transposed motif.
- Comparative evaluation of tool wear and microscopic analysis of the cutting edge and tip of the milling cutter after each processing, concluding that in *Engrave* milling, wear affects the cutting edge more, while in the *V-Carve* method, wear on the milling cutter tip is greater.
- Hierarchizing wood species and processing parameters through experimental research on the surface quality of curved contours processed on CNC and calculating the length affected by visually detectable machining defects.
- Evaluating the quality of milled surfaces by measuring and interpreting roughness parameters Ra, Rk, Rv, Rvk, Rpk, Rsk, and Wa on samples from four wood species, milled at angles of 0°, 15°, 30°, 45°, 60°, 75°, and 90° relative to the wood fiber direction, at different milling conditions.
- Experimental testing of coloring and finishing methods to highlight the milled ornaments.
- Decomposing digital models into colors for laser engraving.
- Determining the method of correlating colors from traditional textile patterns with those of the models transposed onto the wooden surface through laser engraving, depending on the laser beam power, as a result of a color study.
- Microscopic measurement of the wood burning depth to determine the maximum allowable sanding thickness that can be removed without affecting the low-power engraved pattern.
- FTIR investigations for surfaces subjected to laser engraving with powers of 10%, 30%, 50%, 70%, and 100%, for analyzing the chemical changes that occur.
- A comparative study of ornamentation through CNC milling and laser engraving provides the opportunity to choose between the two methods, considering aesthetic, technological, and economic aspects.

- Dissemination of research results through the publication of 5 ISI-indexed articles and participation in 3 international scientific conferences, symposiums, fairs, and presentations.
- Technology transfer of the ornamentation method to the company NORDARIN Piatra Neamț, with the stylized version of the "Ram's Horns" motif presented together with the symbol's story at the Milan International Furniture Fair 2022 (Fig. 6.1).


a b

Fig. 6.1. RAM furniture set made of oak wood: a - table; b - bench.

### 6.3. Dissemination of Results

**A. Indexed ISI/BDI papers**

**1.** Lungu, A., Ispas, M., Brenci, L., Răcășan, S., Coșereanu, C. (2021). Comparative study on wood CNC routing methods for transposing a traditional motif from the Romanian textile heritage into furniture decoration, Applied Sciences, 11(15), 6713. DOI: 10.3390/app11156713 (ISI journal), https://www.mdpi.com/2076-3417/11/15/6713/htm

**2.** Lungu, A., Androne, A., Gurău, L., Răcășan, S., Coșereanu, C. (2021). Textile heritage motifs to decorative furniture surfaces. Transpose process and analysis, Journal of Cultural Heritage 52, pp. 192-201 (ISI journal), https://www.sciencedirect.com/science/article/pii/S129620742100159X

**3.** Lungu, A., Timar M.C., Beldean E.C., Georgescu, V.S., Coșereanu, C. (2022). Adding value to maple (Acer pseudoplatanus) wood furniture surfaces by different methods of transposing motifs

from textile heritage, Coatings, 12(10), 1393. DOI: 10.3390/coatings12101393 (ISI journal), https://www.mdpi.com/2079-6412/12/10/1393

**4.** Gurău, L., Coșereanu, C., Timar, M.C., Lungu, A., Condoroțeanu, C.D. (2022). Comparative surface quality of maple (Acer pseudoplatanus) cut through by CNC routing and by CO2 laser at different angles as related to the wood grain, Coatings, 12(12), 1982. DOI: 10.3390/coatings12121982 (ISI journal), https://www.mdpi.com/2079-6412/12/12/1982

**5.** Lungu, A., Gurău, L., Coșereanu, C. (2023). Evaluation of CNC Routed Surface Quality of Maple (Acer Pseudoplatanus) and Oak (Quercus Robur L.) with Different Milling Angles as Function of Grain Orientation. Articolul este în recenzie la BioResources (ISI journal)

**B. Papers published in journals and conference proceedings with references**

**1.** Lungu, A., Puskás, M., Coșereanu, C. (2020). Convergences between the traditional motifs of the Romanian and Mexican textile heritage, Redefining Community in Intercultural Context, 9(1), pp. 41-46, „Henri Coanda" Air Force Academy Publishing House: http://www.afahc.ro/ro/rcic/2020/rcic'20/volum_2020/041-046%20Lungu%20et%20al.pdf

**2.** Lungu, A., Androne, A., Gurău, L., Coșereanu, C. (2021). Simulating traditional textile heritage motifs by applying CAD-CAM-CAE tool for furniture decoration, Matec Web of Conference, 341, 04012. DOI: 10.1051/matecconf/202134304012, https://www.matec-conferences.org/articles/matecconf/abs/2021/12/matecconf_mse21_04012/matecconf_mse21_04012.html

**3.** Lungu, A., Gurău, L., Georgescu, S., Coșereanu, C. (2021). Computer-aided methods for furniture decoration with traditional motifs of textile heritage, IOP Conference Series: Materials Science and Engineering, 1235, 012041. DOI: 10.1088/1757-899X/1235/1/012041 https://iopscience.iop.org/article/10.1088/1757-899X/1235/1/012041

**C. Presentations at various events**

**1.** SCiEFEST 2019 - Science and Creative Industries Festival, 3rd edition, George Barițiu County Library Brașov, Presentation: *Traditional Motifs from Țara Bârsei*, November 26, 2019.

**2.** "Researchers' Night 2020," Research and Development Institute of Transilvania University of Brașov, *Technique of Chilim Stitch Point*, November 27, 2020. Link: https://icdt.unitbv.ro/ro/noaptea-cercetatorilor/991-tehnica-punctului-de-cus%C4%83tur%C4%83-chilim.html,

**3.** Interactive Seminar "Traditions in Contemporary Times - Valorization of Elements from Traditional Costumes in Contemporary Fashion," within the Erasmus project "Support to European Quality Assurance in Vocational Education and Training (EQAVET) National points," Maria Baiulescu Technical College Brașov, Paper: *Traditional Symbols from Țara Bârsei*, February 25, 2021.

**4.** Project "Reviving and Renewing the Traditional Romanian Spirit in the Souls of Children from Old Brașov," Association for Culture and Conservation of Heritage and Traditions "Old Brașov," Presentation: *Traditional Motifs from Țara Bârsei*, August 19, 2021.

**5.** *Digitization, a Method of Perpetuating Traditional Motifs from Textile Heritage*, presentation at the Annual Session of Scientific Communications, Ethnography section, National Museum of the Eastern Carpathians, Sf. Gheorghe, Covasna, "Ethnographic Heritage of the Eastern Carpathians - Research, Conservation, Valorization," December 9, 2021.

**6.** *Digitization, a Method of Perpetuating Traditional Motifs from Textile Heritage*, at the AUDITORIUM Hall of UTBv, on the festive day of Transilvania University of Brașov, March 1, 2022.

**7.** AFCO 2022 - Furniture Conservation Association Conference, Paper: *Possibilities of Transposing Traditional Motifs from Textile Heritage of Țara Bârsei and Surroundings to Furniture*, May 10, 2022, distinguished with an award in Section XI – Doctoral Candidates.

**8.** *Digitization, a Method of Perpetuating Traditional Motifs from Textile Heritage*. The Lost Path, Urban Civilization Museum of Brașov, November 17, 2023.

**9.** *Digitization, a Method of Perpetuating Traditional Motifs from Textile Heritage*, Ethnography Museum of Săcele, May 13, 2023.

**D. External Mobility**

**1.** **November 21 - 30, 2021**: Romanian Pavilion - **Expo Dubai 2020** "Tradition reloaded: connect visually and emotionally with Romanian craftworkers as they create art." Responsible for traditional embroidery workshops.

**2.** **March 10 - 20, 2022**: Romanian Pavilion - **Expo Dubai 2020** "Tradition reloaded: connect visually and emotionally with Romanian craftworkers as they create art." Coordinator of the group.

**3.** **June 7 - 12, 2022**: **Milan International Furniture Salon 2022**, Fiera Milano Rho, Italy. Furniture developed in partnership with Nord Arin company.

### 6.4. Future Research Directions

- Exploring the use of other wood materials (colored mass MDF, veneered panels, composite materials, etc.).
- Investigating alternative methods for transferring patterns onto wood surfaces (thermal transfer printing, stenciling).
- Continuation of research on sanding and finishing ornamental surfaces engraved with laser.

- Further research on finishing ornamental surfaces obtained through milling, while preserving the original colors of traditional motifs.
- Applying color studies to combine a greater number of colors in traditional motif compositions and using computer software for selection and engraving on various wood species.
- Processing ornaments through wood surface cutouts.
- Exploring other decorative techniques (marquetry, inlay, Yosegi Art).
- Expanding the motif database to include patterns from other regions of the country.
- Exploring convergences between traditional motifs from Romanian heritage and those from other cultures, applied on wood surfaces.
- Testing a wider range of CNC milling parameters on the wood species used in this study.
- 3D modeling and application of ornaments on spatial objects.
- Integrating ornaments in the decoration of prototype furniture pieces and adapting them for visualization in virtual reality.
- Developing an application for integrating ornamental furniture in interior design through augmented reality.

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