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Digitalization of Design and Machining Processes of Wood Carving Products Using CAD/CAM/CNC Technologies for Preservation of Minangkabau Culture

Fadli Islami,[a] and Agus Sutanto,[a,*]

[a)] *Mechanical Engineering Department, Faculty of Engineering, University of Andalas, Indonesia*

*Corresponding author: agussutanto@eng.unand.ac.id

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ABSTRACT

The preservation and development of Minangkabau wood carvings are facing significant challenges due to a decline in skilled carvers and the deterioration of existing artworks caused by natural factors and aging. If these trends continue, the unique motifs of Minangkabau carving risk becoming extinct. A digital preservation initiative is essential to document and store these motifs for future generations. This study proposes the application of CAD/CAM/CNC technologies to facilitate this preservation effort. By digitizing original carvings into 2D and 3D formats, this research aims to create accessible digital archives of Minangkabau motifs. Given the vast array of available designs and motifs, this research will focus on four selected motifs based on their complexity and philosophical significance. These motifs will be produced using traditional manual carving and modern CNC methods, specifically the V-Carving technique. The processing time required for each method will be documented throughout the manufacturing process to evaluate their respective advantages and drawbacks. The research findings show that although the CNC method can significantly improve efficiency, requiring an average processing time three times faster than the manual method, it may not fully replicate the skill and precision of traditional carving, especially in achieving intricate relief details and unique motif shapes. This approach seeks to preserve cultural heritage while enhancing the understanding of integrating traditional artistry with contemporary technology.

KEYWORDS: *Minangkabau wood carving, CAD, CAM, CNC, CNC Router Machine, Culture Preservation.*

1.0 INTRODUCTION

Minangkabau wood carving is a traditional art form from West Sumatra, Indonesia, deeply rooted in the Minangkabau culture, known for its matrilineal society and rich heritage. Wood carving in Minangkabau is not merely decorative. It has held the cultural and spiritual significance. Carvings often reflect the Minangkabau people's values, beliefs, and historical narratives. The art has been shaped by a blend of indigenous practices and external influences, including Indian and Islamic motifs [1],[2]. Carving materials usually come from hardwood such as teak, mahogany, surian, and jackfruit. The choice of wood often reflects both aesthetic and practical considerations. Traditional tools for producing wood carvings manually include chisels, knives, and hammers, which the craftsmen themselves often make.

Most traditional Minangkabau wood carving products are found in furniture, home décor, religious artifacts, and traditional objects such as traditional Minangkabau houses like Istano Basa Pagaruyung, as shown in Figure 1, which feature elaborate wooden facades adorned with wood carvings [3]. Common motifs of Minangkabau wood carving include floral patterns, geometric shapes, and representations of local flora and fauna. For example, as seen in the motifs on the Rumah Gadang, there are carved motifs called *Pucuak Rabuang*, *Itiak Pulang Patang, Tupai Managun, Ula Gerang, Tatandu Manyasok*. The carved motifs were symbolically created to convey implicit messages to everyone who saw them, as well as being a means of educating and reprimanding the public [4],[5].

Traditional Minangkabau wood carvings are an architectural heritage passed down from generation to generation and adorn the walls of Rumah Gadang, offices, and various furniture. Each carving contains teachings and philosophies that reflect the Minangkabau way of life. However, many Rumah Gadang have been neglected or converted over time, leading to a decline in public awareness and appreciation of these cultural artifacts. This lack of interest is exacerbated by the misconception that carvings are only relevant to Rumah Gadang, limiting demand for other applications [6].

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The preservation and development of traditional wood carvings, including those of the Minangkabau, face significant challenges due to the high costs, extensive time required for production, and the scarcity of suitable wood. These factors discourage prospective carvers from pursuing the craft, as the financial rewards do not match the effort involved. Consequently, the younger generation is often reluctant to use traditional carving techniques. Additionally, the lack of standardization in carving practices complicates efforts to promote and preserve this art form. Similar challenges are observed in other countries, such as Malaysia [7] and Ghana [8], where traditional wood carvings also require protection and support from stakeholders. This study also highlights the need for concerted efforts to address these issues and safeguard the cultural heritage associated with traditional wood carving. Especially the use of the latest technology that can provide solutions to these issues [9].

To address the challenges facing Minangkabau wood carvings, it is crucial to promote awareness and appreciation, thereby fostering pride in this cultural heritage. This study proposes digitizing the design and manufacturing process for Minangkabau carvings using CNC (Computer Numerical Control) technology integrated with CAD/CAM systems. By implementing this approach, the preservation and relevance of these wood carvings for future generations can be more assured. Similar initiatives have been explored in the literature, such as those by Gulati et al. in India [10], Lungu et al. in Romania [11], and Sood et al. [12], which highlight efforts to revive interest in traditional crafts while integrating modern technology with traditional artistry [13-16]. This study conducts ongoing revival efforts to preserve traditional techniques while adapting to modern tastes, creating a fusion of traditional and contemporary designs. Wood carving is a significant source of economic income for many artisans, contributing to the local economy and promoting cultural tourism.

This research aims to create a digital model of the design and machining process of various typical Minangkabau wood carving motifs, leveraging advanced CAD/CAM/CNC technology. Then, this research also compares the results of Minangkabau wood carvings produced using CAD/CAM/CNC technology with those produced using conventional manual carving techniques. These objectives provide a comprehensive framework for articulating the significance of this research in the context of regional cultural preservation and technological advancement.

Figure 1: Traditional wood carvings
at the Minangkabau houses (*Rumah Gadang*)

2.0 RESEARCH METHOD

2.1 Materials and Equipment

The wood material used to make the sample is Surian wood (toona sinensis), as shown in Figure 2. Surian trees are known for their rapid growth, making them a sustainable choice for timber. The Surian is commonly utilized in Indonesia for boats, houses, and furniture. The texture of Surian wood is often compared to teak, which is known for its smooth finish and natural luster. It also has good durability (grade IV/V) and strength properties (grade IV). The size of the Surian wood sample used is 800 mm (length) x 230 mm (width) and 30 mm (thickness). The main equipment used in this research is a CNC router machine. The CNC router has a machine power specification of 3 kW, 3000 x 1500 mm working area, 2.2 kW spindle power, spindle water cooler cooling system and PC-based Mach3 control system. The CNC Router bit used in this research consists of a V-bit and ball nose end mill.

There are several places to conduct this research. Data collection on Minangkabau wood carving motifs was conducted at the Istana Basa Pagaruyung in Batusangkar, West Sumatra. The making of several wood carving samples manually by artisans was carried out at the Minang Maketek Jagad Carving Studio in the Koto Tinggi Baso, Agam Regency, West Sumatra. Meanwhile, the process of making carvings using CNC router machines will be carried out at the Jaya CNC Workshop on Hang Lengkir Street, Batu IX Village, Tanjungpinang, Riau Island.

2.2 Research Stages

The research is conducted in several stages as follows:

1. Wood carving motif selection and analysis,
2. Making samples of wood carvings manually,
3. Wood carvings produced using CAD/CAM/CNC technology,
4. Evaluation of the finished products.

This research began by studying existing literature on Minangkabau wood carving techniques, motifs, and the use of CAD/CAM/CNC technology in traditional wood carving crafts. The collection of data on wood carving motifs was carried out through field surveys in several places, such as the *Basa Pagaruyung Palace in Batusangkar*, the *Rumah Gadang* in Bukittinggi, government buildings, and the grand mosque, which uses Minangkabau wood carving motifs.

Figure 2: Surian wood

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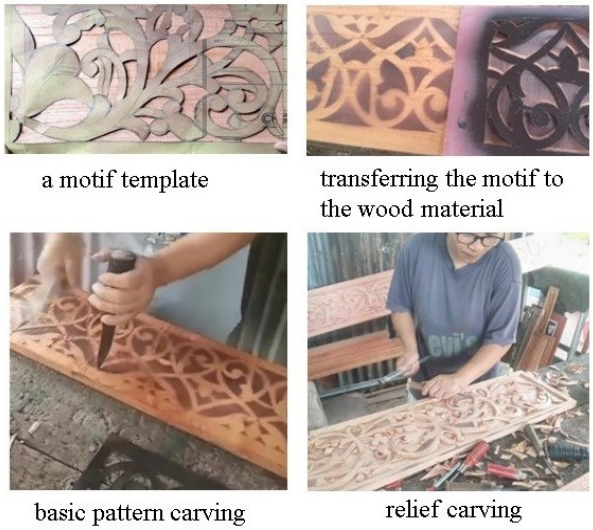

Figure 3: Making wood carving manually

After the survey is conducted, the next stage is determining the type of motif that will be used as the object of research. This is done because the number of Minangkabau carving motifs is very large and diverse, so it is prioritized for several motifs to be studied. The selection of motifs to be used as research objects is analyzed based on the criteria of the level of complexity and depth of cultural meaning as well as the frequency of motif use in buildings and cultural entities in West Sumatra.

Making wood carving samples manually by artisans is carried out at the *Minang Maketek Jagad* Carving Studio in the Koto Tinggi Baso, West Sumatra. Manually making wood carvings is carried out in several stages (Figure 3). The initial stage is creating physical motif templates, which guide the artisan during the carving process. Then, the process stage is continued by transferring the motif template to the wood material. The basic pattern carving is done by removing some of the wood material according to the image reference that has been marked on the material. The relief carving process is a further process after the basic pattern carving. The final process is finishing to smooth the carved surface using sandpaper. All stages of the making are documented, and the processing time is measured.

Wood carvings produced using CAD/CAM/CNC technology begins with creating a 2D digital model using CAD software. This stage has several steps until a valid model is produced with CAM software for the machining automation stage. Firstly, photographing wood carving objects with specific motifs was carried out to obtain digital data (photos) in JPG (Joint Photographic Experts Group) data format for each wood carving motif that was the object of research. Wood carving motifs in JPG files are exported into graphic design software (CorelDraw). At this stage, the JPG file will be scaled according to the original size of the engraving made manually, and then a tracing process will be carried out (the process of following the line pattern of the engraving). The final file resulting from this process is saved in DFX (Drawing Exchange Format) format. DXF is a vector file format that is widely used across different CAD software and enables data interoperability with other CAM software.

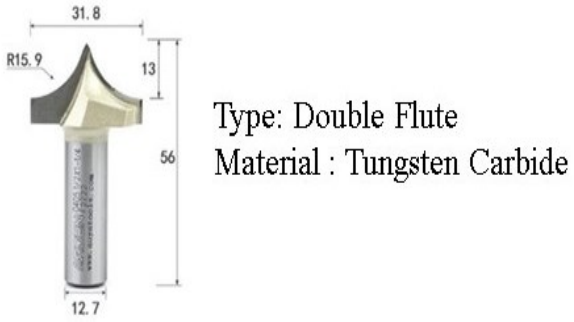

Figure 4: V-bit cutting tools

Once the CAD model is created in DXF format, the next step involves importing these files into CAM software, such as MasterCam or ArtCam. At this stage, it's crucial to determine the dimensions and initial position of the workpiece. A comprehensive machining plan is essential, encompassing toolpath planning, selection of cutting tools, and the establishment of machining parameters for the CNC router machine. In this study, the carving method used is the V-carving method which employs V-bit cutting tool as illustrated in Figure 4. The CAM software then generates the corresponding G-Codes based on the selected machining method. Users can run simulations to visualize the carving process, ensuring that no collisions or errors occur during machining.

The next stage in this research is the carving process carried out by a CNC router machine. This stage begins with preparing the CNC router by ensuring that the machine is calibrated and the cutting tools and selected bits are installed correctly. The wood piece must be clamped to prevent movement during carving, and the origin (zero point) of the CNC router machine must be set first (typically at the corner of the wood piece). Furthermore, the CNC machine executes the programmed tool path to carry out the wood carving process.

The final step of this research involves evaluating the finished products using CNC and manual carving methods. Key factors for comparison include processing time, accuracy, detail, surface finish, consistency, and overall quality. Processing time assesses the time taken to complete each method, highlighting the efficiency of CNC machining versus manual carving. Detail means to evaluate the level of intricacy and complexity achievable with each technique, particularly in fine features. Surface finish includes comparing the smoothness and overall appearance of the surfaces produced by each method. Consistency is analyzing the uniformity of results across multiple pieces each method produces.

3.0 RESULT AND DISCUSSION

The selection of Minangkabau wood carving objects for this research was carried out by field observations to see the carving motifs in the Pagaruyung palace, and then the wood carving motifs will be grouped based on the number of these motifs found or installed in the Pagaruyung palace. Table 1 shows 10 Minangkabau wood carving motifs that are widely found in the Pagaruyung Palace. In general, this motif carries significant symbolic meanings and also serves as a visual representation of Minangkabau values, beliefs, and way of life.

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Table 1: Minangkabau wood carving motifs in the Pagaruyung Palace

Wood carving motif	the place where the motif is attached
Jala Taserak	windows and doors
Sirih Gadang	ceiling
Lumuik Anyuik	front and inner walls
Aka Cino	front and inner walls
Aka Tagah Duo Ganggang	front and inner walls
Kaluk Paku Kacang Balimbing	front and inner walls
Rajo Dan Tigo Selo	front walls
Carano Kanso	front and inner walls
Sikambang Manih	front walls

The motifs selected as the object of research were conducted through a questionnaire to 20 knowledgeable respondents who have valuable perspectives on the complexity and philosophical meanings behind the motifs. The selected motifs based on the criteria are *Aka Tangah Duo Gagang, Sikambang Manih, Kaluk Paku Kacang Balimbing,* and *Aka Cino.*

3.1. Manual Wood Carving

Artisans initiate the wood carving process by designing physical motif templates that guide their work. These templates are transferred onto the wood, indicating where the carvings will be executed. The artisans then meticulously remove sections of wood according to the marked designs to establish the basic patterns. Once the basic pattern is complete, they proceed with relief carving, enhancing the piece with added depth and intricate detail. T

Manual wood carving methods excel in achieving intricate details and smooth finishes, highlighting the artisan's skill and creativity (Figure 5). This study focused on the use of surian wood, with dimensions of 800 x 230 mm, to explore the time efficiency of manual carving techniques. The results, presented in Table 2, show the processing time for several selected wood carving motifs.

Figure 5: The result of manual wood carving

Table 2: Processing time of manual wood carving

wood carving motif	processing time (minute)	
	basic pattern carving	Relief carving
Aka Tagah Duo Ganggang	90	60
Sikambang Manih	120	100
Kaluk Paku Kacang Balimbing	100	120
Aka Cino	120	90

3.2 Digitalization of Design Using CAD

Digitalizing wood carving motif designs into 2D CAD models involves several key procedures that streamline the design process. Digital images are taken from high-resolution photos of wood carving. Then, the digital images in JPG format are imported into CAD software (CorelDRAW). The drawing tools in the CorelDRAW trace over the imported images, creating vector outlines of the motif. Refinement of the traced outlines is needed to ensure smooth lines and accurate curves. The 2D CAD model should be ensured that it fits the intended size and proportions for carving. The finalized 2D CAD design is saved in the appropriate format (e.g., DXF) for integration with manufacturing and CNC machines.

The design digitization process for producing a 2D CAD model of the *Sikambang Manih* carving motif is illustrated in Figure 6. This process involves the meticulous conversion of traditional wood carving designs into digital formats using CAD software, enabling the creation of precise, scalable models. The *Sikambang Manih* motif, along with several other traditional designs, was digitally captured to preserve the intricate patterns and cultural significance of Minangkabau wood carvings. This digitization allows for easier reproduction and adaptation of these motifs for modern applications while maintaining their cultural integrity.

In addition to *Sikambang Manih*, 2D CAD models were also produced for three other Minangkabau carving motifs: *Aka Tagah Duo Ganggang, Kaluk Paku Kacang,* and *Aka Cino*. By creating these digital representations, the study aims to safeguard and promote Minangkabau wood carving heritage in the face of changing craftsmanship practices. The 2D CAD models not only serve as a tool for preservation but also provide a foundation for further exploration into the use of digital technologies in traditional art forms.

3.3 Machining Processes Using CAM/CNC

2D motif designs using CAD (Computer-Aided Design) software are subsequently transformed into machine-readable instructions through CAM software, specifically MasterCam. The CNC router utilizes the V-Carving technique, characterized by specific parameters: a spindle speed of 22,000 RPM, feed rates of 1,200 mm/min, a cutting depth of 6 mm, and the use of a V-bit cutting tool. The wood carving results of the *Kaluk Paku Kacang Balimbing* and *Aka Cino* motifs using the V-Carving method demonstrate a successful blend of efficiency and detail, as illustrated in Figure 7. This technique encompasses both pattern and relief carving, enabling the creation of intricate details, such as the gaps in leaf bones, though not as refined as those produced by manual methods. Overall, V-Carving provides a faster processing time while still delivering quite satisfactory detail in narrower reliefs, making it a valuable approach for wood carving applications.

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Figure 6: Digitalization of carving motif design

Figure 7: Wood carving results with CAD/CAM/CNC technology

3.4 Discussion

The bar chart in Figure 8 illustrates the processing times for creating four Minangkabau wood carving motifs using both traditional manual methods and modern CNC techniques enhanced by CAD/CAM automation. The results demonstrate a significant disparity in processing times between the two approaches. On average, manual carving by artisans requires over 3 hours to complete one motif. In contrast, the CNC V-carving method reduces this time to less than 1 hour, showcasing its remarkable efficiency, nearly four times faster than the manual method. This analysis highlights the advantages of CNC technology, especially the V-carving method, in increasing production efficiency while preserving Minangkabau wood carving art.

The differences in the quality of carvings produced by manual techniques versus those created with a CNC machine, focusing on the level of detail each method can achieve. Manual carving allows artisans to use sharp, fine chisels that can be finely controlled for intricate detailing. The precision and dexterity of a skilled artisan enable them to produce highly detailed and smooth features that are difficult to replicate by machine. These manual techniques offer a tactile and flexible approach, where the artisan can constantly adjust their movements to refine the carving at a granular level, ensuring fine details in every aspect.

On the other hand, CNC machining operates based on programmed instructions and predetermined bit sizes, which limits its ability to achieve the same level of fine detail. The typical V-bit used in CNC routers has a fixed size and shape, restricting the precision, which can carve finer features. Although CNC routers are efficient and can produce complex patterns, their mechanical nature means they are less adaptable to the nuances that a human hand can provide during manual carving. The larger dimensions of the bit can result in coarser lines and less intricate detailing, especially in areas requiring high precision.

The comparison between manual and CNC carving highlights the trade-offs between craftsmanship and machine efficiency. While CNC routers offer consistency and speed, manual carving stands out for its ability to capture detailed, delicate features due to the direct control the artisan has over their tools. This study emphasizes that while machines can replicate certain designs efficiently, the depth and subtlety of detail found in hand-carved works remain unmatched in comparison to machine-produced carvings. The intricate craftsmanship achieved through manual methods is valued for its fine artistry, showcasing the unique abilities of human touch in sculptural design.

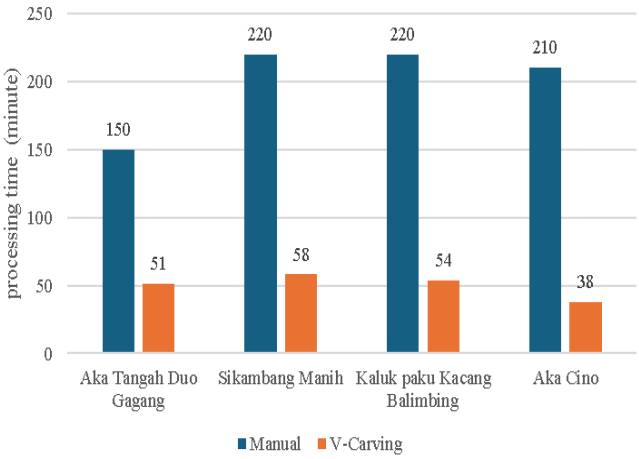

Figure 8: Comparison of processing times

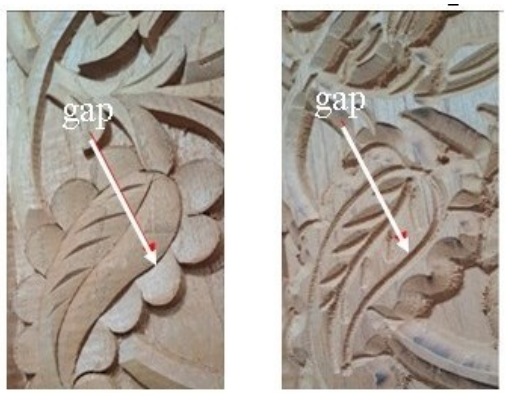

Figure 9: Geometric differences of the two methods

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As a result, while CNC methods may enhance efficiency, they may not match the nuanced craftsmanship and precision of manual carving, underscoring the importance of traditional techniques in producing high-quality wood carvings. As illustrated in Figure 9, manual carving can achieve a gap size of up to 1 mm, whereas the V-carving method produces a gap of 4 mm. This demonstrates that manual carving can create detailed and unique shapes, reinforcing its value in the art of wood carving.

Minangkabau wood carvings showcase the unique artistry and flexibility of manual carving, where the carver's direction and technique create diverse geometric shapes and relief angles. While rich in tradition, this method often results in an uneven surface due to the nature of hand cutting. In contrast, V-Carving with CNC technology uses a fixed V-bit chisel angle, resulting in a fixed relief angle and a consistently flat surface. These two methods highlight different characteristics: the manual approach emphasizes craftsman skill and individuality, while the CNC technique emphasizes precision and uniformity.

This study also highlights observations regarding the CNC carving process using the V-Carving method. One significant finding is that the word carving surface is susceptible to burning, primarily due to the angular shape of the V-bit cutting edge. As the depth of the cut increases, the contact area between the V-bit cutting tool and the material also grows, leading to elevated heat generation. This phenomenon underscores the importance of careful depth of cut control and tool selection to mitigate potential damage to the carved surfaces while optimizing the quality of the final product.

4.0 CONCLUSION

In conclusion, integrating CAD/CAM/CNC technology into designing and fabricating Minangkabau wood carvings represents a significant advancement in cultural preservation. This innovative approach not only protects traditional motifs and patterns for future generations but also improves the accuracy and efficiency of reproduction. By utilizing digital approaches, artisans can maintain the authenticity of their craft while adapting to contemporary demands, ensuring that the rich heritage of Minangkabau woodcarving continues to thrive in a modern context. This study also highlights the differences between manual carving by artisans and using CNC routers to create Minangkabau wood carvings. While manual methods allow for greater detail, smoothness, and unique motifs, they are time-consuming. In contrast, applying CNC routers will expedite production and ensure consistency in motif shapes but still require further finishing to produce more detailed carving motifs. In addition, finishing with a CNC router at a very high speed will increase heat generation so that the wood surface is susceptible to burning.

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