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Research Paper

# Selection of Material and Manufacturing Technology for *Batik Canting* Stamps Based on Multi-Criteria Decision-Making Methods

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**Abstract**

This study aimed to develop alternative materials and technologies for making *canting* stamps used in producing *batik canting* (stamped batik) to transfer hot wax from the pan to the fabric. Previous researchers have studied materials such as wood, aluminum, multiplex, acrylic, and acrylonitrile butadiene styrene (ABS). Manufacturing technologies have also been analyzed, including manual manufacturing, computer numerical control (CNC) milling, laser cutting, and additive manufacturing. However, none of these materials and technologies were considered suitable alternatives for copper canting stamps. This paper proposes Conductive ABS-Electroformed By Copper (CABS-EBC) through additive manufacturing and electroforming processes as alternative material for canting stamps. A multi-criteria decision-making (MCDM) approach was used to assess alternative materials and technologies. The alternatives and criteria were calculated using the Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE) techniques. Besides this, assessment was also carried out based on expert opinions. The results showed that copper was the most suitable material, with Closeness = 1.000, Yi = 0.995, and Phi = +1.00. Meanwhile, CABS-EBC ranked second, with Closeness = 0.627, Yi = 0.864, and Phi = +0.50. The selected technology was additive manufacturing combined with electroforming, with Closeness = 0.700, Yi = 0.895, and Phi = +0.39. By using MCDM on the material-technology development candidates it was found that CABS-EBC processed with additive manufacturing is capable of substituting copper as a canting stamp material. It is expected that the production capacity of the traditional manufacturing process can be enhanced by adopting these new materials and technologies.

**Keywords:** *batik; multi-criteria decision-making (MCDM; Preference Ranking Organization Method of Enrichment Evaluation (PROMETHEE); canting stamp; Simple Additive Weighting (SAW); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).*

## Introduction

Batik is a type of traditional Indonesian fabric developed using the wax-resist dying technique. The *canting* method is utilized to print intricate designs onto the fabric, employing three different types of batik, depending on the wax application method: hand drawn (*canting tulis*) batik; stamped batik; or a combination of both [1]. The process of developing stamped batik is similar to block printing of fabric from India, with the main difference being in the waxing and coloring process [2]. The canting stamp tool consists of a handle, a frame, and a batik pattern to transfer hot wax from the pan to the fabric. Based on the superior ability to evenly spread wax, copper is traditionally the most popular material for canting stamps [3]. Its high thermal conductivity enables efficient transfer of hot wax to the fabric. The flexibility of the material also allows the formation of intricate batik motifs, with its strength ensuring the durability of the canting stamp tool over time.

According to a preliminary report, the copper canting stamp, which involves thin copper sheets curved to form the batik motif, exhibits low productivity. It takes two to four weeks to complete the manufacturing process,


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depending on the size and complexity of the pattern [3]. Optimization and standardization of this production process is required, to increase the efficiency and economic value of batik production [4]. Most stamped batik industries depend heavily on the skills of the canting craftsmen, whose numbers are decreasing due to a lack of regeneration and the high cost of raw materials [5]. This leads to delays in the provision of canting stamps, prompting some industries to implement wood or paper stamps. In this context, the challenges encountered by canting craftsmen should be majorly addressed for the improvement of canting stamp productivity to ensure the sustainability of the stamped batik industry.

The potential of canting stamp equipment development is highly significant for the batik industry, which comprises approximately 47,000 industrial units across Indonesia [6]. This shows that stamped batik is specifically popular among relevant organizations due to its faster production speed compared to hand drawn batik. In this case, each batik motif typically requires one or more canting stamps, including the *klowong* and *nutup* designs. Although alternative materials such as aluminum, wood, multiplex, acrylic, ABS, and paper, have been explored as alternative materials for canting stamp, none have managed to replace copper as the primary material for the manufacturing tools. Attempts have also been made to optimize the stamp production process using various methods, such as manual manufacturing, laser cutting, computer numerical control (CNC) machining, and additive manufacturing. One of these attempts included the use of conductive ABS filament created by advanced additive manufacturing and copper electroforming processes. It means that a conductive ABS on the inside and a copper was used as a coating for the canting stamp on the outer surface. The present study aimed to provide a suitable material substitute for copper in the stamped canting method while maintaining its effectiveness in producing high-quality batik designs. This was carried out by using multi-criteria decision-making (MCDM) methods for selecting the most suitable material and manufacturing technology. In determining the selection of alternatives based on the criteria used in MCDM, expert opinion assessment was also conducted [7].

MCDM is a mathematical process used to evaluate a set of alternatives regarding multiple criteria. This method has broad applications in various field, including engineering, operations research, management, and finance. Some of its common applications include investment portfolio decision-making [8], vendor/supplier selection [9, 10], and location selection [11], as well as construction [12]. Moreover, several developed MCDM methods have previously been used to determine the most suitable material and manufacturing technology. This includes the compilation of a report on the materials selection of automobiles in full cycle against the background of green manufacturing [13] using various applications. These applications included PROMETHEE [14], gear materials selection [15], and turbine materials selection using PROMETHE-GAIA [16]. Polymer composite material was used for engineering applications through the AHP-MOORA method in [17], accompanied by the implementation of SAW, MOORA, TOPSIS, and VIKOR in [18]. Some of the technologies selected based on such methods were machined parts assembly [19] and sustainable disposal technology selection based on SBWM (stratified best-worst method) [20]. Other technologies are machining parameter selection in milling epoxy granite composite regarding only AHP [21], with an advanced manufacturing system emphasizing AHP and TOPSIS [22]. Pham and Nguyen [23] used adaptive fuzzy proportional integral sliding control for a two-tank interaction system.

To achieve the study objectives, a framework was developed by following a series of steps, namely problem formulation, selection of analytical methods, and calculation. According to the problem formulation, a thorough review of the existing literature on materials and technology development was conducted, accompanied by a gap analysis. The performance of each canting stamp material was then assessed, with analysis of the relationship between manufacturing technology and application of the material. In the next step, the proposed material and technology were explored with the formulated criteria for material and manufacturing technology. SAW, TOPSIS and PROMETHEE were used to select the most suitable material and technology for the manufacturing process toward the substitution of copper as canting stamp material. After performing the calculations based on the theoretical basis of SAW, TOPSIS, and PROMETHEE, the results obtained were evaluated and conclusions were drawn.

## Literature Review

### Material and Manufacturing Technology of Stamp Canting

Figure 1 shows a flexible and durable canting stamp made of copper. Such canting stamps have an excellent spread rate of wax due to copper's high thermal conductivity and capacity. However, its major drawbacks are high cost and low productivity, where the manual manufacturing process usually takes between two and four weeks to be completed. To address these challenges, various studies have been conducted on the development of alternative materials and manufacturing technologies for producing canting stamps. These efforts included the implementation of the following materials and techniques: (1) wooden canting stamps with different manual production techniques [24]; (2) wooden canting stamps manufactured by CNC milling [3]; (3) multiplex canting stamps produced by CNC milling [25]; (4) acrylic canting stamps manufactured by CNC milling [3]; (5) paper canting stamps ([23, 27]; and (5) ABS filament canting stamps produced by additive manufacturing (AM) [27].

**Figure 1** Copper canting stamp [28].

Since every canting stamp material is related to the manufacturing process, the development of a method depends on the available equipment. Copper and paper can be crafted traditionally ([4,23]), while aluminum and wood ([3, 25, 26]) multiplex and acrylic [22], as well as ABS can be machined by CNC milling [29], laser cutting (LC) and additive manufacturing, respectively.

The quantitative parameters of various materials are shown in Table 1, showing two physical properties of the canting stamp, namely thermal conductivity and melting point. This indicates that the canting stamp material should be sufficiently able to withstand and store heat. Copper has high thermal conductivity (401 W/m.K) and a high melting point (1,084 °C), providing resistance to operational conditions up to 130 °C. Although aluminum has high thermal conductivity and a high melting point, it possesses poor performance in the canting process (Table 2). Its processing cost is also high when operated at high temperature (150 °C). This high thermal operation makes aluminum unsuitable for use as canting stamp material.

The gap analysis of materials and manufacturing technologies for canting stamps is shown in Table 1.

**Table 1** Gap analysis of material base on literature review.

| Properties | Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Copper [4]** | **Wood [3]** | **Aluminium [30]** | **ABS [27]** | **Multiplex [25]** | **Paper [31]** | **Acrylic [3]** |
| Thermal conductivity (W/m.K) | 401 | 0.17 | 237 | 0.33 | 0.17 | 0.06 | 0.25 |
| Melting point (°C) | 1,084 | - | 660 | 220 | - | - | 160 |
| Hardness (Brinnel) | 35 | 2.6 – 7.0 | 15 | 5.6-15.3 (Vickers) | 1,6 | - | 34 |
| Temperature Hot Wax | ±130°C | ±130 °C | ±150 °C | ±110 °C | ±158 °C | ±130 °C | ±65 °C |
| Productivity (minutes) | 6,720 | 450 | 6,747 | 1,757 | 1,440 | - | - |
| Cost production ( Rp .000) | 2,000 | 120 | 1,870 | 570 | 61 | - | - |

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Table 2 shows the qualitative performance assessment of canting stamp material parameters based on expert opinion. This includes four parameters that determine the quality of the canting stamp. Firstly, Material Structure emphasizes the ability of the equipment to form a complete canting cap. This explains that a complete canting stamp structure includes the ability to develop the following, (1) a *klowong* motif with curves or lines with a thickness of at least 1 mm; (2) an *isen-isen* inner motif containing short lines or dots of 1 mm thickness; and (3) a sign or dropper tool in the form of a 1-mm diameter wire, which acts as a marker to facilitate repeated canting. Secondly, Heat Resistance prioritizes the manufacturing performance under hot wax temperatures. During the application of wax onto batik cloth, the canting stamp is often exposed to temperatures of up to 130 °C. This means that the canting cap should be able to withstand high temperatures and remain resistant to heat toward successfully transferring the liquid wax onto the fabric. Thirdly, Stamping Quality focuses on the spread rate of the wax, with category determination emphasizing the amount of wax mass content. The amount of wax mass content exhibits the tasting quality with full indication of closing blocks, lines, and dots. This is because the development of the batik motif images determines the quality of the tasting output[32]. Fourthly, Lifetime refers to the material's durability, where the canting stamp should be able to withstand prolonged and frequent implementation. This is due to the repeated usage of the canting stamps by the batik artisans to apply wax onto the fabric. Copper canting stamps are highly durable and can last for years, emphasizing the importance of evaluating the relevant physical properties.

**Table 2** Performance of canting stamps.

| Performance | Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Copper** | **Wood** | **Aluminium** | **ABS** | **Multiplex** | **Paper** | **Acrylic** |
| Structure of canting | Complete | Not complete | Not complete | Complete | Not complete | Not complete | Not complete |
| Heat resistance | Good | Good | Good | Bad | Good | Good | Bad |
| Quality of stamping [32] | Good | Average | Bad | Average | Average | Good | Bad |
| Lifetime | Good | Good | Good | Average | Average | Bad | Average |

The relationship between materials and manufacturing technologies is highlighted in Table 3. It shows that not all materials can be effectively processed with the same manufacturing technology. Each manufacturing technology also has its own set of advantages and disadvantages, including production speed and cost, ability to produce a canting stamp, and investment requirements. Furthermore, the canting stamp production process varies regarding the implemented material and manufacturing technology. Manual systems are capable of producing canting stamps from copper, wood, multiplex, and paper, while being unsuitable for developing acrylic, ABS, or ABS-EBC equipment. The completion of the manual process is usually between two and four weeks. CNC machines can work on copper, multiplex, and acrylic materials, not on multiplex, paper, ABS, or ABS-EBC materials. These machines are unable to produce the whole canting stamp structure. Meanwhile, laser cutting is capable of working on wood, multiplex, acrylic, and paper but it cannot be used for the whole canting stamp structure. Additive manufacturing (AM) has been used with ABS and ABS-EBC materials, producing a more efficient complete canting structure.

**Table 3** Relationship between materials and manufacturing technology of canting stamps.

| Manufacturing Technology | Material | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Copper** | **Wood** | **Multiplex** | **Acrylic** | **Paper** | **ABS** | **ABS-EBC** |
| Manually | √ | √ | √ | - | √ | - | - |
| CNC | √ | √ | - | √ | - | - | - |
| LC | - | √ | √ | √ | √ | - | - |
| AM | √ | - | - | √ | - | √ | √ |
| AM + Electroforming | √ | - | - | √ | - | √ | √ |

## Multi-Criteria Decision-Making

Multi-criteria analysis is used when alternatives and criteria need to be minimized or maximized with conflicting condition decisions. This involves the use of flexible instruments when compared to purely mathematical methods of optimization [33]. Eleven MCDM methods were analyzed, including SAW, TOPSIS, and PROMETHEE[34]. The analysis showed that each method has its advantages, disadvantages, and application areas. Most studies implemented SAW (Simple Additive Weighting), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) to select alternatives. Each method has its strengths and weaknesses, with different techniques being appropriate for different decision-making situations.

SAW is a straightforward method that is easy to use and understand, making it suitable for simple decision-making problems. This method is commonly implemented by assigning weights to each criterion and calculating the score for each alternative. The alternative with the highest score is selected. TOPSIS is a more complex method and prioritizes the distance of each alternative from the ideal and worst solutions. This method is specifically useful for situations involving multiple criteria with trade-offs often observed between them. Meanwhile, PROMETHEE is a technique allowing the decision-maker to rank the alternatives based on preference and identify the degree of conflict between criteria. This technique is flexible and capable of handling various types of data. It is specifically suitable for problems prioritizing quantitative and qualitative criteria.

In this study, SAW, TOPSIS, and PROMETHEE were selected due to their effectiveness for different types of decision-making problems. The selection also depended on their ability to help decision-makers in considering multiple criteria when selecting alternatives. This approach considers various qualitative and quantitative factors that should be determined to identify the optimal solution. For instance, factors such as cost/price and process quality are frequently encountered criteria in decision-making scenarios. In these scenarios, groups of experts often assign different weights to the criteria based on their significance in specific cases [35]. To obtain a matrix of criteria and alternatives, the opinions of five to ten experts are often considered. A higher number of experts commonly leads to decreased consistency or greater inconsistency values [7].

Figure 2 shows the general procedures in MCDM [36]. This includes a decision matrix consisting of alternatives (rows) and criteria (column), normalization, weighting, criteria weighting, positive and negative solutions, relative closeness, and ranking.

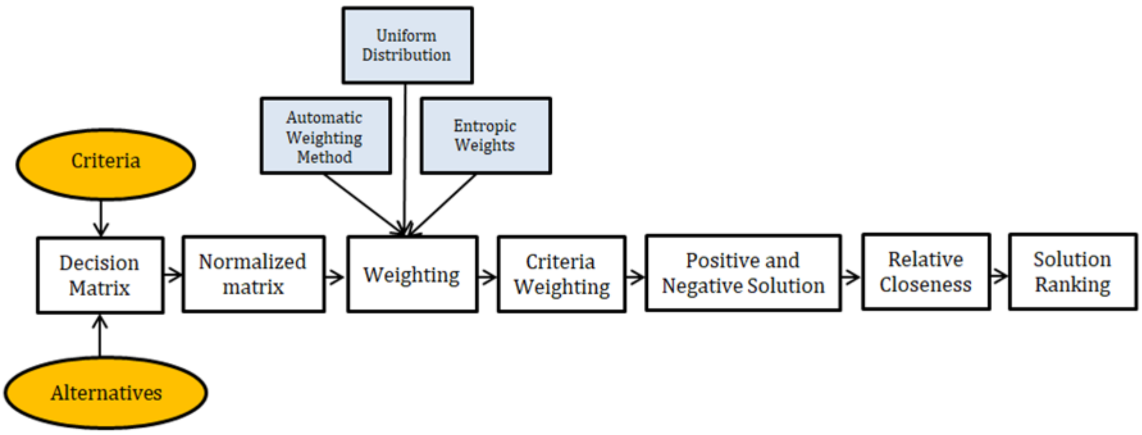


**Figure 2** General procedure in MCDM methods [36].

This study was conducted using the SAW, TOPSIS, and PROMETHEE approaches. This was because of the consideration of SAW as a value function established through a simple addition of the scores representing the goal achieved under each criterion, multiplied by the specific weights [37]. It is also able to compensate among criteria, it is intuitive to decision makers, arithmetically simple, and does not require a computer program [34]. TOPSIS is an approach used to identify the alternative closest to the ideal and negative solutions in a multi-dimensional computing space [37,34]. According to Simanaviciene and Ustinovichius [38], this approach has a higher sensitivity than SAW. Meanwhile, PROMETHEE is an outranking method developed by Brans and Vincke [39], later improved by Brans *et al*. [40]. It is based on a simple concept that is easier to implement than the other presently available multi-criteria analysis techniques [41]. Based on these properties, the Visual PROMETHEE Academic software was experimentally implemented in this study.

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### Problem Formulation

The demand for canting stamps in the batik industry, encompassing 47,000 businesses throughout Indonesia, is presently beyond the available supply. This is because of the scarcity of canting stamp makers, attributed to slow regeneration and the escalating cost of copper, leading to expensive canting stamps. The manual production of canting stamps causes reduced productivity and extended waiting periods, typically ranging from two to four weeks. To address these challenges, the development of novel materials and manufacturing technologies is imperative to reduce the cost of canting stamp production while enhancing productivity. Although previous works explored alternative canting stamp materials, none were able to match the performance of copper canting stamps. This led to the presentation of an innovative solution involving the use of a conductive ABS material generated through additive manufacturing and copper electroforming processes. This novel approach is able to significantly enhance the availability, affordability, and quality of canting stamps in the batik industry.

### Proposed Material and Manufacturing Technology

This paper proposes a conductive ABS filament produced using additive manufacturing and copper electroforming processes, named CABS-EBC (Conductive ABS-Electroformed by Copper). Regarding the plastic filament to select, ABS is considered a strong option despite pure ABS being an insulator. This is because the electrical conductivity of ABS can be enhanced by incorporating carbonaceous filler into the composite. For instance, several reports have shown that this can significantly increase the electrical conductivity of ABS/graphene-nanocomposite to 10-9 S/cm at 30 wt.% [42]. ABS is also a strong and durable chemically resistant polymer, with electrical conductivity adding to its versatility. Furthermore, the method suits aesthetic preferences. Compared to other filaments (such as PLA, PETG, HIPS, PVA, and nylon), ABS provides better impact properties and slightly higher heat distortion effect resistance. Thus, this method is a favorable choice for applications requiring durability, chemical resistance, and electrical conductivity [43]. An advantage of using additive manufacturing is the speed of the production process and the ability to build complicated batik patterns. Conductive ABS as canting stamp material is unsuitable for operating at molten wax temperature. To achieve the required heat resistance, ABS should be coated with a more durable material such as a metal. Copper was selected as the coating material due to its excellent resistance to high temperatures as well as its compatibility with the conductive properties of the ABS material.

The copper coating treatment enhances the heat resistance of the conductive ABS, aligning it with the characteristics of traditional copper canting stamps. Copper was selected as the coating material due to its exceptional thermal conductivity, high melting point, and close resemblance to the commonly used traditional canting stamps. In this case, a smoother transition for the artists accustomed to traditional stamps is enabled, providing a familiar experience while using the new tool. This method represents a novel approach to crafting canting stamps, successfully facilitating access to essential tools for batik artisans.

## Methods

This study aimed to evaluate different alternative materials and manufacturing technologies for producing canting stamps. In this case, the analyzed materials were copper, wood, acrylic, ABS, and CABS-EBC. The evaluated alternative manufacturing technologies were manual manufacturing, CNC machining, laser cutting, additive manufacturing (AM), and AM-electroforming. These options were selected based on previous studies. To accomplish the research objectives, the methodology followed the framework outlined in Figure 3. This indicates that the initial step was the identification of the research problems through a comprehensive literature review. After the research problems were identified, the subsequent step entailed precise research problem formulation. The resolution of the research problems necessitated the implementation of a review of previous literature to provide a solid theoretical foundation.

The next step involved the formulation of material and technology criteria, where several standards and alternatives were selected through the MCDM approach. The criteria were the following, 1) the ability to develop detailed batik motifs and structures (*klowong* and *isen-isen*) ($C_m1$); 2) the ability of the material to transfer hot wax form the pan to the fabric ($C_m2$); 3) the material having good heat retention, thermal conductivity and capacity ($C_m3$); 4) the ability of the canting stamp to transfer the hot wax to the fabric ($C_m4$); and 5) the canting stamp must have 115-130 °C hot-wax heat and impact resistance ($C_m5$).

After the determination of the material selection criteria, a manufacturing technology standard was developed. In this step, the different manufacturing technologies were applied to the different materials. Table 3 presents the relationship between the materials and the manufacturing technologies related to canting stamps.

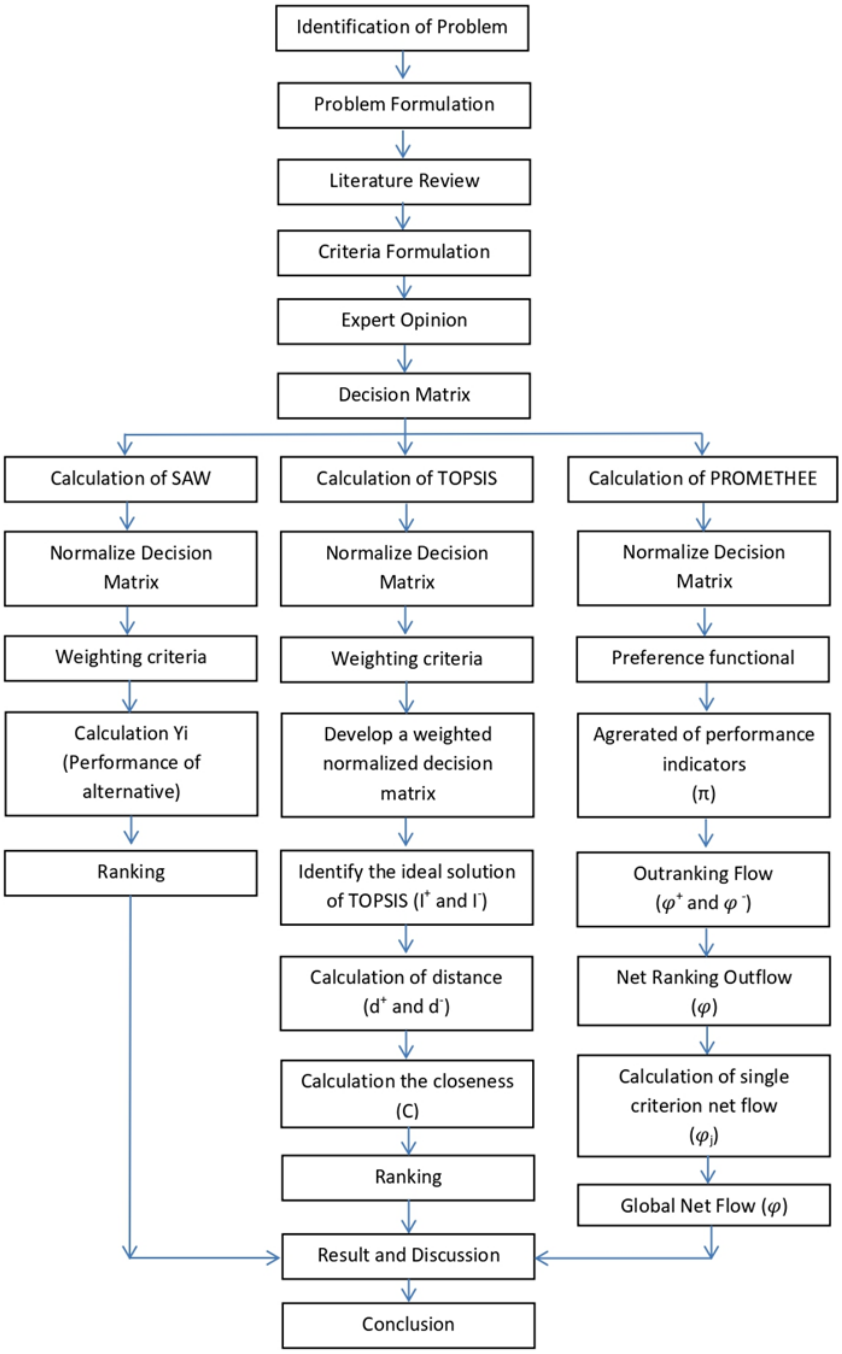


**Figure 3** Methodology steps followed in this study.

The criteria considered in the manufacturing technology selection were the following, 1) productivity ($C_t1$); 2) the ability to produce a detailed batik motif and complete canting stamp structure (*klowong* and *isen-isen*)

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($C_t2$); 3) production costs ($C_t3$); 4) novelty ($C_t4$); and 5) investment costs ($C_t5$). Furthermore, advanced treatment of conductive ABS material using copper electroforming is proposed. This contributed to the determination of the most suitable material for the canting stamp manufacturing technology using the decision matrix shown in Eq. (1).

$$X = \begin{bmatrix} o & C_1 & C_2 & \cdots & C_n \\ A_1 & X_{11} & X_{12} & \cdots & X_{1n} \\ A_2 & X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & A_{m1} & A_{m2} & \cdots & X_{mn} \end{bmatrix} \tag{1}$$

Calculations were performed for each method, i.e., SAW, TOPSIS, and PROMETHEE, after compilation of the decision matrix.

## Application of SAW method

Stage 1: Normalization of the decision matrix [18, 44] using Eqs. (2) and (3) for beneficial and non-beneficial criteria, respectively,

$$X'_{ij} = \frac{X_{ij}}{X_j^+} \tag{2}$$

$$X'_{ij} = \frac{X_{ij}}{X_j^-} \tag{3}$$

where:

$X'_{ij}$ = normalized performance value of the i-th alternative regarding the j-th criteria
$X_{+j}$ = maximum value of $X_{ij}$ for criteria j
$X_{-j}$ = minimum value of $X_{ij}$ for criteria j

Stage 2: Assign weights to each criterion.
Stage 3: Calculate the performance score of each alternative.

The normalized values of all criteria were multiplied by their weight and added up for each alternative using the SAW method. The performance score for each alternative was calculated through Eq. (4),

$$Y_i = \sum_{j=i}^{n} W_j \times X'_{ij} \tag{4}$$

where,

$W_j$ = the weight of the criteria
$Y_i$ = the performance score of i-th alternative regarding all criteria.

The ranking of alternatives was then provided based on the values of $Y_i$, with the highest ranked first.

## Application of TOPSIS Method

Stage 1: Normalize the decision matrix [18, 45] using Eqs. (5) and (6) for beneficial and non-beneficial criteria, respectively,

$$X'_{ij} = \frac{X_{ij}}{X_j^+} \tag{5}$$

$$X'_{ij} = \frac{X_{ij}}{X_j^-} \tag{6}$$

$X'_{ij}$ = normalized performance value of the i-th alternative regarding the j-th criteria
$X_{+j}$ = maximum value $X_{ij}$ of criteria j
$X_{-j}$ = minimum value $X_{ij}$ of criteria j

Stage 2: Assign weights to each criterion.

Stage 3: Create a weighted normalized decision matrix using Eq. (7).

$$D = \begin{bmatrix} D_{11} & D_{12} & \cdots & D_{1n} \\ D_{21} & D_{22} & \cdots & D_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ D_{m1} & D_{m2} & \cdots & D_{mn} \end{bmatrix} \tag{7}$$

where, $D_{ij} = X'_{ij} \times W_j$

$W_j$ = the weight of criteria j

Stage 4: Identify the ideal solutions of TOPSIS, where I+ and I- = PIS (Positive Ideal Solution) and NIS (Negative Ideal Solution), calculated through Eqs. (8) and (9), respectively,

$$I_j^{+} = (\max D_{i1}, \max D_{i2}, \max D_{i3}, \ldots, \max D_{in}) \tag{8}$$

$$(1 \leq i \leq m)$$

$$I_j^{-} = (\max D_{i1}, \max D_{i2}, \max D_{i3}, \ldots, \max D_{in}) \tag{9}$$

$$(1 \leq i \leq m)$$

Stage 5: Calculate the distance of all alternatives, with PIS and NIS using Eqs. (10) and (11), respectively,

$$d^{+} = \sqrt{\sum_{j=1}^{n} \left(D_{ij} - I_j^{+}\right)^2} \tag{10}$$

$$(1 \leq i \leq m, 1 \leq j \leq n)$$

$$d^{-} = \sqrt{\sum_{j=1}^{n} \left(D_{ij} - I_j^{-}\right)^2} \tag{11}$$

$$(1 \leq i \leq m, 1 \leq j \leq n)$$

Stage 6: Calculate the closeness rating of all alternatives regarding PIS, using Eq. (12),

$$\text{Closeness (C)} = \frac{d^{-}}{d^{-} + d^{+}} \tag{12}$$

Stage 7: Assign a rank to the alternatives based on the closeness value, with the highest coefficient being ranked first.

## Application of PROMETHEE

The PROMETHEE method is a decision matrix comprising the performance score of the i-th alternative regarding the j-th criterion. This supplements the pair-wise comparisons from the basic preference structure of the PROMETHEE method. Comparisons were also carried out on the deviations between two alternatives on a specific criterion, with a preference allocated and unallocated to 1 and 0, respectively. Therefore, a larger deviation implied a greater preference, with real numbers varying between 0 and 1. The preference functions for beneficial and non-beneficial criteria were also obtained, using Eqs. (13) and (14), respectively [16],

$$P_j(a, b) = F_j\left[d_j(a, b)\right] \quad \forall a, b \epsilon A \tag{13}$$

$$P_j(a, b) = F_j\left[-d_j(a, b)\right] \quad \forall a, b \epsilon A \tag{14}$$

where, $d_j$ (a,b) = [$g_j$(a)-$g_j$(b)] and $0 \leq Pj \leq 1$

When the evaluation matrix was ready, the aggregated performance indices were obtained through Eq. (15),

$$\begin{cases} \pi\,(a, b) = \sum_{j=1}^{n} P_j(a, b) w_j \\ \pi(b, a) = \sum_{j=1}^{n} P_j(b, a) w_j \end{cases} \tag{15}$$

The positive and negative outranking flows were obtained using Eq. (16) and (17), respectively,

$$\varphi^{+}(a) = \frac{1}{m-1} \sum_{x \epsilon A} \pi(a, x) \tag{16}$$

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$$\varphi^{-}(a) = \frac{1}{m-1}\sum_{x\epsilon A}\pi(a,x) \tag{17}$$

The net ranking outflow was then obtained using Eq. (18),

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \tag{18}$$

Eq. (19) was subsequently used for the calculation of single-criterion net flow by considering only a specific standard,

$$\varphi_j = \frac{1}{m-1}\sum_{x\epsilon A}\left[P_j(a,x) - P_j(x,a)\right]w_j \tag{19}$$

The global net flow of an alternative was then acquired through Eq. (20),

$$\varphi(a) = \sum_{j=1}^{n}\varphi_j(a)w_j \tag{20}$$

## Data

Data were obtained by surveying six batik experts from CHB (Center for Handicraft and Batik), an institute dedicated to the research and development of batik. In this institute, the experts are mostly specialized in materials and canting stamp production. These experts ranged in age and organizational tenure from 23-60 and 9-20 years, respectively. Most of them also held positions as researchers and engineers in machinery and batik production. Furthermore, the experts possessed extensive knowledge of canting stamp techniques and the batik making process. Their assessments were obtained using a questionnaire-based and a matrix-based approach. The results showed that the matrix-based approach yielded better scores, due to allowing the experts to directly compare multiple alternatives regarding the same criteria. Meanwhile, the questionnaire-based approach led to less consistent answers from them. According to the specific criteria, the experts were tasked with evaluating alternative materials and manufacturing technologies. The participants were subsequently instructed to assign weights to each criterion, considering both the material and the manufacturing technology aspects. The average values from the expert assessment were organized into decision matrices, as presented in Tables 4 to 7.

**Table 4** Decision matrix of materials.

| Material alternative | Criteria of material | | | | |
|---|---|---|---|---|---|
| | $C_m1$ | $C_m2$ | $C_m3$ | $C_m4$ | $C_m5$ |
| Copper | 93.33 | 96.67 | 95.00 | 94.17 | 95.83 |
| Wood | 61.67 | 71.83 | 66.00 | 72.33 | 77.50 |
| Acrylic | 66.17 | 65.33 | 67.67 | 67.00 | 75.83 |
| ABS | 74.17 | 66.67 | 64.50 | 68.17 | 73.33 |
| CABS-EBC | 83.83 | 82.50 | 82.67 | 83.67 | 78.83 |

**Table 5** Normalized weight of criteria of materials.

| | $C_m1$ | $C_m2$ | $C_m3$ | $C_m4$ | $C_m5$ |
|---|---|---|---|---|---|
| Weight | 0.20 | 0.28 | 0.24 | 0.16 | 0.12 |

**Table 6** Decision matrix of manufacturing technologies.

| Manufacturing technology alternative | Criteria of manufacturing technology | | | | |
|---|---|---|---|---|---|
| | $C_t1$ | $C_t2$ | $C_t3$ | $C_t4$ | $C_t5$ |
| Manually | 70.00 | 95.00 | 81.33 | 50.17 | 89.17 |
| CNC | 88.33 | 70.83 | 70.00 | 79.17 | 55.00 |
| LC | 89.17 | 68.33 | 69.17 | 78.33 | 55.00 |
| AM | 84.17 | 80.17 | 71.67 | 83.33 | 67.50 |
| AM + Electroforming | 77.83 | 85.50 | 74.33 | 85.00 | 70.83 |

**Table 7** Normalized weight of criteria of manufacturing technologies.

| | $C_t1$ | $C_t2$ | $C_t3$ | $C_t4$ | $C_t5$ |
|---|---|---|---|---|---|
| Weight | 0.20 | 0.29 | 0.22 | 0.18 | 0.11 |

## Calculation

### Calculation of SAW

The calculation of SAW was in line with the methodological application in Section 2.1 and presented in Tables 8 and 9.

**Table 8** SAW for materials.

| Material | $C_m1$ | $C_m2$ | $C_m3$ | $C_m4$ | $C_m5$ | $Y_i$ |
|---|---|---|---|---|---|---|
| Copper | 1 | 1 | 0.9827 | 1 | 1 | 0.995 |
| Wood | 0.6607 | 0.7431 | 0.6827 | 0.7681 | 0.8086 | 0.723 |
| Acrylic | 0.7089 | 0.6758 | 0.7000 | 0.7115 | 0.7913 | 0.707 |
| ABS | 0.7946 | 0.6896 | 0.6672 | 0.7238 | 0.7652 | 0.718 |
| CABS-EBC | 0.8982 | 0.8534 | 0.8551 | 0.8884 | 0.8226 | 0.864 |

**Table 9** SAW for manufacturing technologies.

| Manufacturing Technology | $C_t1$ | $C_t2$ | $C_t3$ | $C_t4$ | $C_t5$ | $Y_i$ |
|---|---|---|---|---|---|---|
| Manually | 0.7850 | 1 | 1 | 0.5902 | 1 | 0.875 |
| CNC | 0.9907 | 0.7456 | 0.8607 | 0.9314 | 0.6168 | 0.829 |
| LC | 1 | 0.7193 | 0.8504 | 0.9216 | 0.6168 | 0.819 |
| AM | 0.9439 | 0.8439 | 0.8811 | 0.9804 | 0.7570 | 0.878 |
| AM + Electroforming | 0.8729 | 0.9000 | 0.9139 | 1 | 0.7944 | 0.895 |

**Table 10** Normalized matrix of materials.

| Material | $C_m1$ | $C_m2$ | $C_m3$ | $C_m4$ | $C_m5$ |
|---|---|---|---|---|---|
| Copper | 0.544 | 0.558 | 0.558 | 0.542 | 0.531 |
| Wood | 0.360 | 0.415 | 0.388 | 0.416 | 0.169 |
| Acrylic | 0.386 | 0.377 | 0.398 | 0.385 | 0.420 |
| ABS | 0.432 | 0.385 | 0.379 | 0.392 | 0.407 |
| CABS-EBC | 0.489 | 0.476 | 0.486 | 0.481 | 0.437 |

### Calculation of TOPSIS

The calculation of TOPSIS was in line with the methodological application in Section 2.2 and presented in Tables 10 to 13.

**Table 11** Weight criterion matrix of materials.

| Material alternative | Criteria | | | | | Distance | | Closeness |
|---|---|---|---|---|---|---|---|---|
| | $C_m1$ | $C_m2$ | $C_m3$ | $C_m4$ | $C_m5$ | $d^+$ | $d^-$ | C |
| Copper | 0.107 | 0.156 | 0.137 | 0.088 | 0.062 | 0.000 | 0.091 | 1.000 |
| Wood | 0.071 | 0.116 | 0.095 | 0.067 | 0.020 | 0.083 | 0.012 | 0.125 |
| Acrylic | 0.076 | 0.105 | 0.097 | 0.062 | 0.049 | 0.077 | 0.030 | 0.281 |
| ABS | 0.085 | 0.107 | 0.093 | 0.064 | 0.047 | 0.074 | 0.031 | 0.295 |
| CABS-EBC | 0.096 | 0.133 | 0.119 | 0.078 | 0.051 | 0.034 | 0.058 | 0.627 |
| $I^+$ | 0.107 | 0.156 | 0.137 | 0.088 | 0.062 | | | |
| $I^-$ | 0.071 | 0.105 | 0.093 | 0.062 | 0.020 | | | |

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**Table 12** Normalized matrix of manufacturing technologies.

| Manufacturing technology alternative | $C_t1$ | $C_t2$ | $C_t3$ | $C_t4$ | $C_t5$ |
|---|---|---|---|---|---|
| Manually | 0.381 | 0.527 | 0.495 | 0.294 | 0.581 |
| CNC | 0.481 | 0.393 | 0.426 | 0.464 | 0.145 |
| LC | 0.485 | 0.379 | 0.421 | 0.459 | 0.358 |
| AM | 0.458 | 0.445 | 0.436 | 0.489 | 0.440 |
| AM + Electroforming | 0.423 | 0.475 | 0.453 | 0.498 | 0.461 |

**Table 13** Weight criterion matrix of manufacturing technologies.

| Manufacture technology alternative | Criteria | | | | | Distance | | Closeness |
|---|---|---|---|---|---|---|---|---|
| | $C_t1$ | $C_t2$ | $C_t3$ | $C_t4$ | $C_t5$ | $d^+$ | $d^-$ | C |
| Manually | 0.072 | 0.153 | 0.109 | 0.053 | 0.064 | 0.042 | 0.066 | 0.614 |
| CNC | 0.091 | 0.114 | 0.094 | 0.084 | 0.016 | 0.064 | 0.036 | 0.362 |
| LC | 0.092 | 0.110 | 0.093 | 0.083 | 0.039 | 0.053 | 0.043 | 0.449 |
| AM | 0.087 | 0.129 | 0.096 | 0.088 | 0.048 | 0.032 | 0.054 | 0.628 |
| AM + Electroforming | 0.080 | 0.138 | 0.100 | 0.090 | 0.051 | 0.025 | 0.059 | 0.700 |
| $I^+$ | 0.092 | 0.153 | 0.109 | 0.090 | 0.064 | 0.092 | | |
| $I^-$ | 0.072 | 0.110 | 0.093 | 0.053 | 0.016 | 0.072 | | |

## Calculation of PROMETHEE

Figure 4 shows the implementation of the visual PROMETHEE Academic software. The material selection calculation was conducted by filling in the data in Tables 4 and 5.

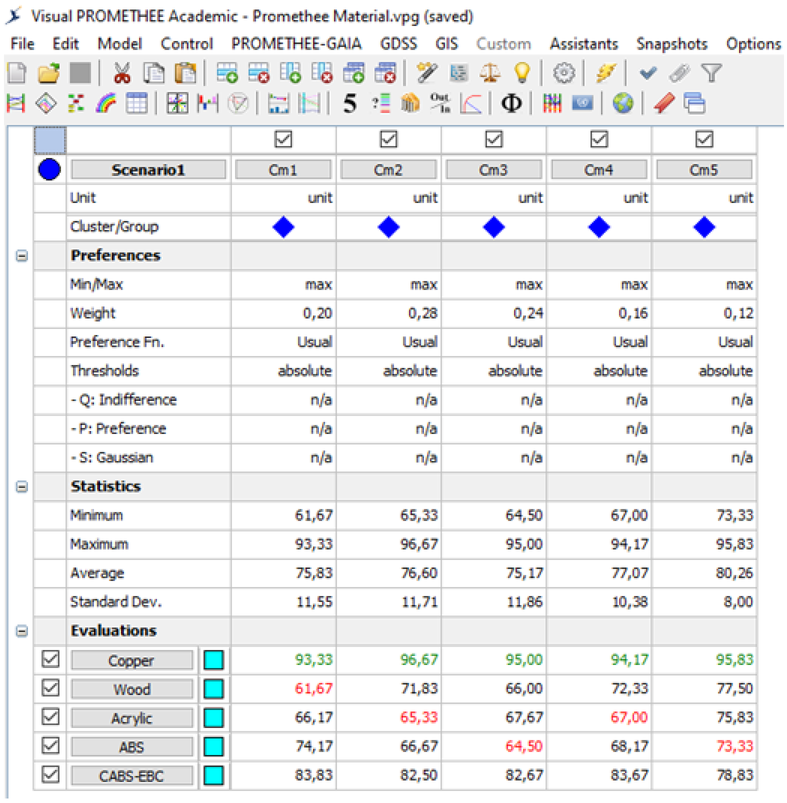



**Figure 4** Input window for canting stamp material selection.

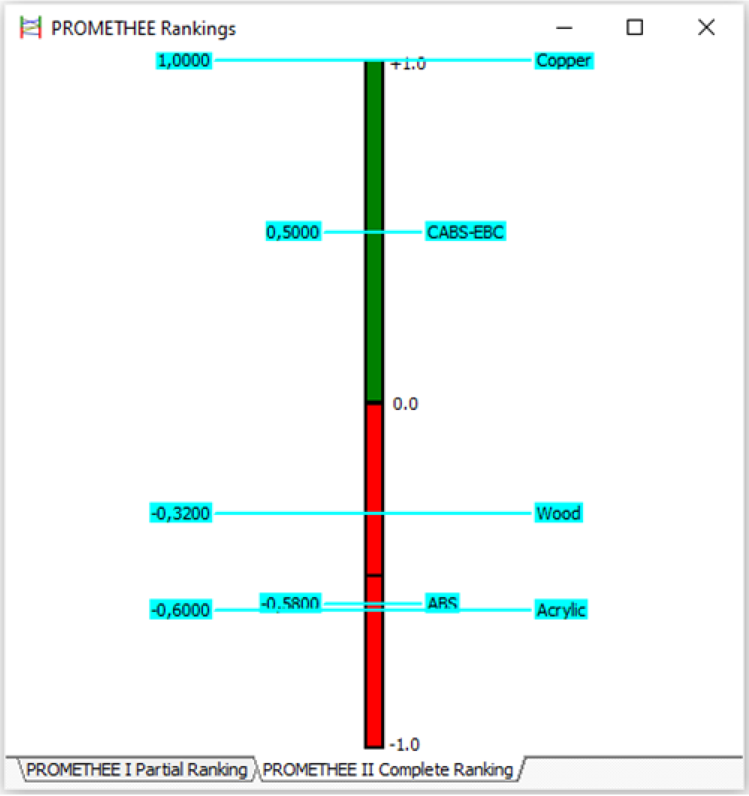
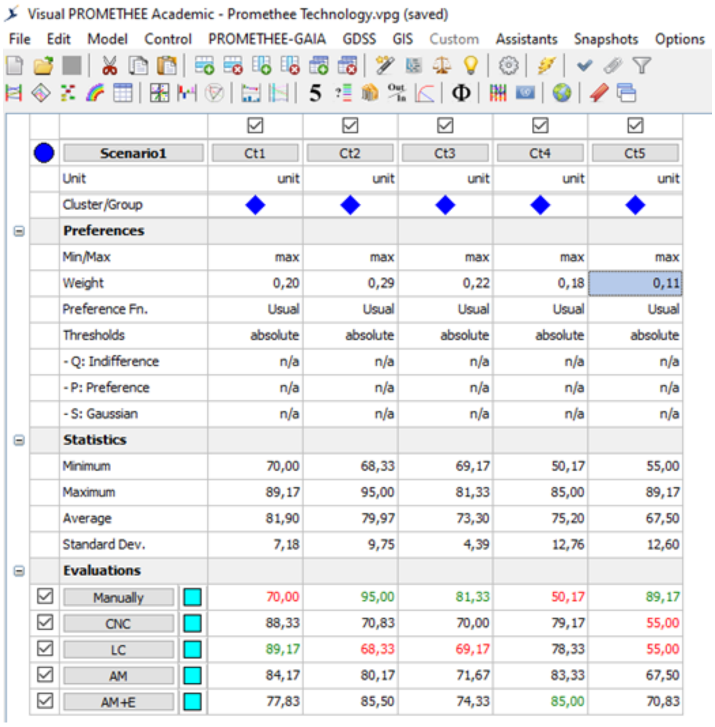



**Figure 5** PROMETHEE II Complete Ranking for canting stamp material.

A visualization of the material selection calculation using PROMETHEE is shown in Figure 5. Furthermore, the manufacturing technology alternatives were analyzed by filling in the data in Tables 6 and 7.


Visual PROMETHEE Academic - Promethee Technology.vpg (saved)

File Edit Model Control PROMETHEE-GAIA GDSS GIS Custom Assistants Snapshots Options

| Scenario1 | Ct1 | Ct2 | Ct3 | Ct4 | Ct5 |
|---|---|---|---|---|---|
| Unit | unit | unit | unit | unit | unit |
| Cluster/Group | | | | | |
| **Preferences** | | | | | |
| Min/Max | max | max | max | max | max |
| Weight | 0,20 | 0,29 | 0,22 | 0,18 | 0,11 |
| Preference Fn. | Usual | Usual | Usual | Usual | Usual |
| Thresholds | absolute | absolute | absolute | absolute | absolute |
| - Q: Indifference | n/a | n/a | n/a | n/a | n/a |
| - P: Preference | n/a | n/a | n/a | n/a | n/a |
| - S: Gaussian | n/a | n/a | n/a | n/a | n/a |
| **Statistics** | | | | | |
| Minimum | 70,00 | 68,33 | 69,17 | 50,17 | 55,00 |
| Maximum | 89,17 | 95,00 | 81,33 | 85,00 | 89,17 |
| Average | 81,90 | 79,97 | 73,30 | 75,20 | 67,50 |
| Standard Dev. | 7,18 | 9,75 | 4,39 | 12,76 | 12,60 |
| **Evaluations** | | | | | |
| Manually | 70,00 | 95,00 | 81,33 | 50,17 | 89,17 |
| CNC | 88,33 | 70,83 | 70,00 | 79,17 | 55,00 |
| LC | 89,17 | 68,33 | 69,17 | 78,33 | 55,00 |
| AM | 84,17 | 80,17 | 71,67 | 83,33 | 67,50 |
| AM+E | 77,83 | 85,50 | 74,33 | 85,00 | 70,83 |

**Figure 6** Input window for canting stamp manufacturing technology selection.

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Figure 7 shows a visualization of the selection of the manufacturing technology using the PROMETHEE method.

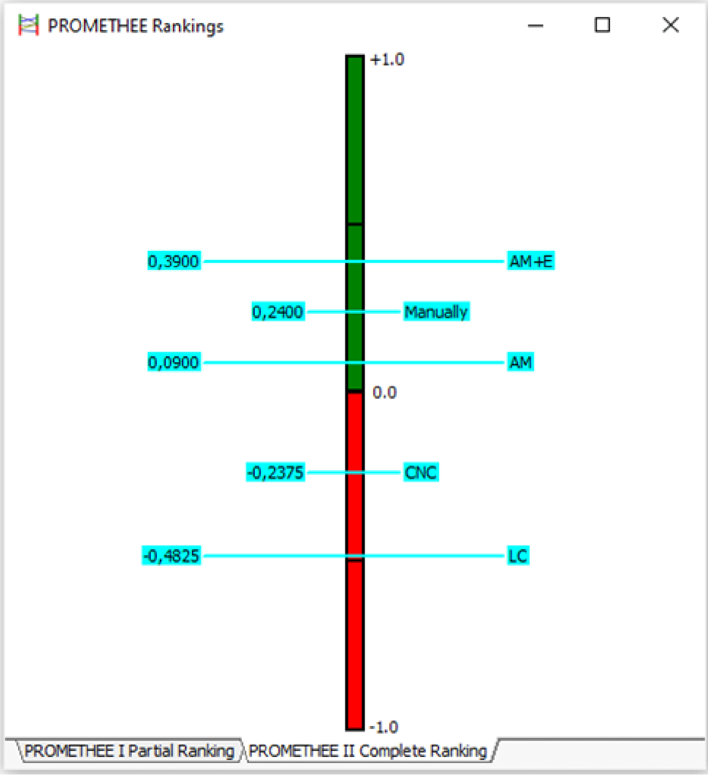


**Figure 7** PROMETHEE II Complete Ranking for canting stamp manufacturing technology.

## Results and Discussion

Based on Table 14, copper was considered the most suitable canting stamp material according to the SAW, TOPSIS, and PROMETHEE methods described in Section 2.4. With the TOPSIS method, copper achieved a perfect closeness value of 1.000, indicating its superiority. Meanwhile, CABS-EBC, ABS, acrylic, and wood scored values of 0.627, 0.295, 0.281, and 0.125, respectively. The SAW method showed that copper attained a Yi value of 0.995, along with CABS-EBC, wood, ABS, and acrylic at 0.864, 0.723, 0.718, and 0.707, respectively. From these results, the experts stated that copper is the most favorable choice of material. In the PROMETHEE method, copper, CABS-EBC, wood, ABS, and acrylic obtained Phi values of +1.00, +0.50, -0.32, -0.58, and -0.60, respectively.

By consistently obtaining the highest score across the evaluated criteria, copper emerged as the preferred material for canting stamp production due to its exceptional properties. Regarding the first material ($C_m1$) related to batik motif development, copper also achieved an impressive value of 93.33, with its soft and tough nature enabling easy formation of intricate batik patterns. Besides this, copper elements can also be effectively joined through soldering [3]. Closely rivalling copper for quality is CABS-EBC, which had a $C_m1$ score of 83.83. This demonstrates its capability to form batik patterns through additive manufacturing, where the production of complex shapes is possible together with the realization of intricate designs, including *klowong* and *isen-isen*.

According to the experts' weighting (Table 5), the highest weight priority was given to criterion number 2 ($C_m2$), which evaluated the capability of the material to effectively transfer hot wax from the pan to the fabric. This criterion holds significant importance because it directly impacts the success of the batik-making process. In this case, copper and CABS-EBC obtained the highest and slightly lower scores of 96.67 and 82.50, demonstrating superior and decreased performance, respectively. Based on the assessment of thermal conductivity and capacity ($C_m3$), copper and CABS-EBC achieved scores of 95.00 and 82.67, respectively. This shows that copper has superior thermal conductivity compared to the other materials according to the opinions of the experts and the data presented in Table 1. To address this disparity, CABS-EBC was specifically developed with a copper-electroforming process to closely match the thermal conductivity and capacity properties of copper. This approach ensures that CABS-EBC attains similar thermal performance as observed in copper.

In the assessment of the canting stamp's ability to effectively transfer hot wax onto fabric ($C_m4$), copper exhibited commendable performance (Table 2) with a score of 94.17, while CABS-EBC attained 83.67. According to the experts, CABS-EBC possesses the capability to approach the performance of copper based on this criterion. According to the material heat and impact resistance assessments, copper is outstanding with a melting point of 1,084 °C, while it is 220 °C for ABS. Since CABS-EBC is an electroformed composite consisting of a conductive ABS core with a copper coat as the outer layer, it benefits from increased heat resistance due to this construction. For this criterion, copper and CABS-EBC had scores of 95.83 and 78.83, respectively. Therefore, the implementation of CABS-EBC (Conductive-ABS Electroformed by Copper) presents an opportunity to potentially replace traditional copper canting stamps. The objective of the copper-electroforming process is also to enhance the conductive properties of ABS by specifically augmenting heat conductivity, strength, and temperature resistance [46].

**Table 14** Rank of materials.

| Material Alternative | TOPSIS | | SAW | | PROMETHEE | |
|---|---|---|---|---|---|---|
| | Closeness | Rank | $Y_i$ | Rank | Phi | Rank |
| Copper | 1.000 | 1 | 0.995 | 1 | +1.00 | 1 |
| Wood | 0.125 | 5 | 0.723 | 3 | -0.32 | 3 |
| Acrylic | 0.281 | 4 | 0.707 | 5 | -0.60 | 5 |
| ABS | 0.295 | 3 | 0.718 | 4 | -0.58 | 4 |
| CABS-EBC | 0.627 | 2 | 0.864 | 2 | +0.50 | 2 |

The manufacturing technology rankings produced by SAW, TOPSIS, and PROMETHEE are presented in Table 15. According to the expert assessments, AM (additive manufacturing) and electroforming ranked as the top choice as canting stamp manufacturing technology, with the selection depending on the specific material involved. In the TOPSIS method, AM-electroforming and AM achieved closeness values of 0.700 and 0.628, respectively. The SAW approach showed that AM-electroforming and AM attained Yi values of 0.895 and 0.878, respectively. Meanwhile the PROMETHEE method, AM-electroforming and AM obtained Phi coefficients of +0.39 and +0.24, respectively.

According to the normalized weight of the criteria for the manufacturing technologies (Table 7), the ability to manufacture a detailed batik pattern and complete canting structure ($C_t2$) is the most important criterion, with a mass of 0.29. In this case, AM and AM-electroforming methods had scores of 95.00 and 85.50, respectively. Despite these results, the experts still believed that manual manufacturing is better than the AM-electroforming approach, as shown in Table 6. Since the criterion weight of the productivity of manufacturing technology ($C_t1$) was set at 0.20, AM-electroforming and AM achieved scores of 77.83 and 70.00, respectively. Based on this result, the experts argued that LC (laser cutting) obtained the highest score, at 89.17, consistent with Table 1, where it has a high productivity rate of 450 mins. Another crucial criterion is production costs ($C_t3$), where the manual method proved to be most cost-effective at 81.33 as it is reliant on simple equipment. Meanwhile, fused deposition AM type production ranked second at 74.33 and 71.67. Additive manufacturing minimizes waste and is relatively inexpensive compared to subtractive methods such as CNS milling. Thus, CNS and LC are considered expensive in terms of production costs.

From the results, the fourth criterion ($C_t4$) evaluated the novelty of the production techniques. This evaluation indicated that AM and AM-electroforming are a new manufacturing technique and a recent advancement, respectively. Since no previous studies have been done on AM-electroforming for canting stamps, a score of 85.00 was obtained concerning this criterion. For the fifth criterion ($C_t5$), investment costs were evaluated, with the manual method requiring the lowest contribution at 89.17. Meanwhile, CNC and LC demanded the highest investments, obtaining a score of 55.00. This shows that the investment value of AM is smaller than for CNC regardless of its relatively new technology status, leading to a score of 70.83 assigned by the experts. Based on the overall calculation of the alternative value with the weight of the criteria, AM-electroforming is considered a high manufacturing technology. This proves that additive manufacturing is a promising

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technology with many advantages. It has already been used to fabricate a canting stamp with ABS [27]. Since no subsequent treatment of the ABS was done, the ABS-based canting stamp did not possess similar performance to that of a copper-based canting stamp. Therefore, an advanced process was provided for the development of canting stamps with copper-electroforming, to improve its conductivity and thermal capacity. According to the experts, this step resulted in positive output, so the combination of CABS-EBC and additive manufacturing achieved good scores.

**Table 15** Ranking of manufacturing technologies.

| Manufacturing Technology Alternative | TOPSIS | | SAW | | PROMETHEE | |
|---|---|---|---|---|---|---|
| | Closeness | Rank | $Y_i$ | Rank | Phi | Rank |
| Manually | 0.614 | 3 | 0.875 | 3 | +0.24 | 2 |
| CNC | 0.362 | 5 | 0.829 | 4 | -0.24 | 4 |
| LC | 0.449 | 4 | 0.819 | 5 | -0.48 | 5 |
| AM | 0.628 | 2 | 0.878 | 2 | +0.09 | 3 |
| AM + Electroforming | 0.700 | 1 | 0.895 | 1 | +0.39 | 1 |

## Conclusions

Multi-criteria decision-making (MCDM) is one of the most accurate methods to support decision making. Specifically, the MCDM method is considered the best technique when there is more than one criterion in the decision-making process. Studies emphasizing the development of materials and manufacturing technologies for the production of canting stamps using an expert approach are rare. In this case, the considered material selection encompassed copper, wood, acrylic, ABS, and CABS-EBC, while the selected technologies included manual manufacturing, CNC, laser cutting, additive manufacturing (AM), and AM-electroforming. To analyze these aspects, three MCDM techniques, namely SAW, TOPSIS, and PROMETHEE, were employed. According to expert opinion and analysis, copper is the most suitable material, with CABS-EBC being a promising alternative. As a new material, CABS-EBC is capable of replacing copper in the production of canting stamps. Regarding the manufacturing technology, AM-electroforming ranked first due to its ability to produce copper-coated conductive ABS canting stamps. This leads to improved conductivity and thermal capacity properties similar to copper.

Additive manufacturing technology also has many other advantages, for which subsequent development is required. Based on the discovery of new materials and manufacturing technologies for canting stamps, the batik industry can produce cheaper, faster, and more durable tools that meet the needs of the sector throughout Indonesia. This is expected to be able to significantly influence the growth and development of the industry. However, several limitations were observed in this study. Firstly, the implemented MCDM method was restricted to three specific techniques, namely SAW, TOPSIS, and PROMETHEE. This limitation was imposed due to the existence of numerous other methods that are capable of yielding different outputs. For instance, AHP (Analytic Hierarchy Process) is an alternative method worth considering, but the pairwise comparison process is a weakness. This proves that an increased number of alternatives and criteria leads to greater difficulties in achieving consistent ratio values. Secondly, the judgments of the experts sourced from the Center for Handicraft and Batik were insufficient. Since only six experts participated in the experiment, the rankings obtained through the MCDM method heavily depended on their subjective opinions when assigning alternative and criteria weights. Considering different outcomes from different experts with different backgrounds, the obtained reports will be more plausible. Thirdly, a limitation emerged during the formulation of the criteria, as the number of specified standards varied based on specific needs and research objectives when addressing material and manufacturing technology selection. From these results, subsequent studies should explore and compare a wider array of materials suitable for additive manufacturing, including metal elements with selective laser-sintering technology.

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