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Multi-Criteria Decision-Making Framework for the Strategic Selection of Digital Manufacturing Machines

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ABSTRACT: Fab Labs and digital manufacturing equipment represent a transformative approach for enhancing manufacturing capabilities in low-income settings. However, the proliferation of alternative machines and rapid technological advancement create significant challenges for digital entrepreneurs. The selection of an appropriate machine is essential to achieve optimal results in digital manufacturing. This study develops a Multi-Criteria Decision-Making (MCDM) framework to strategically select digital manufacturing equipment, addressing key barriers of equipment selection and funding constraints in resource-limited environments. Through a structured methodology combining literature-based criteria identification, expert consultations, and hierarchical decision modeling, the proposed framework comprises three sequential steps: problem structuring, MCDM technique selection, and decision reporting. Our findings highlight critical equipment selection criteria, including accessibility and procurement efficiency, performance, power usage efficiency, and community impact. The MCDM framework enables informed procurement decisions and identifies strategies to cultivate a maker culture essential for community empowerment. By offering practical guidance for optimizing equipment procurement in Fab Labs, this research enhances operational capacity and fosters innovation and resilience in low-income settings, ultimately contributing to broader socio-economic benefits.

KEYWORDS: Fab lab, Technological entrepreneurship, Developing country, AHP, Fuzzy AHP, TOPSIS

1. INTRODUCTION

In an era where digital literacy and technological proficiency are critical, technological entrepreneurship leveraging Fab Labs and digital manufacturing has emerged as a transformative strategy for enhancing manufacturing capabilities in low-income settings. This is particularly crucial in Africa, where a rapidly growing youth population needs relevant skills for the modern economy (García-Ruiz & Lena-Acebo, 2022). This approach aligns with the broader trend of digital transformation in Africa, where equipping the youth with digital skills is seen as crucial for future economic growth (Howard, 2023).

With Africa’s youth population projected to reach nearly 830 million by 2050, the development of digital skills transcends educational goals and becomes an urgent socio-economic imperative. This transformation is essential for boosting youth employment and supporting sustainable economic growth. Interventions across the entire digital ecosystem are needed to prepare low income settings youth for the current and future world of work, reversing trends of informal work and underemployment. This requires a focus on digital transformation through digitalization and the deployment of fourth industrial revolution technologies.

Despite the significant potential of digital manufacturing machines, many developing nations encounter substantial barriers to their adoption and sustainable operation. A prevalent perception exists that digital fabrication technologies are prohibitively expensive, and that only specially qualified professionals possess the skills to purchase and effectively utilize these machines. This misconception limits awareness of the accessible and affordable innovations these technologies can offer, thereby stifling potential avenues for creativity, entrepreneurship, and economic advancement within these communities.

In the context of technological entrepreneurship in Cameroon, three major challenges have been identified: securing funding, selecting appropriate equipment, and promoting a vibrant maker culture. These issues are compounded by complex procurement processes, as seen in Fab Lab UP Cebu in the Philippines, where staff struggle with bureaucratic obstacles related to government anti-corruption regulations and the limited availability of local suppliers (Brun et al., 2018).

Securing funding remains a significant obstacle, as financial resources are often limited in low-income settings, hindering the initial setup and ongoing operations of Fab Labs. Moreover, selecting appropriate equipment is complicated by a lack of awareness about available technologies and their cost implications, which can lead to poor investment decisions and underutilized resources. Lastly, promoting a vibrant maker culture is essential to foster creativity and collaboration within these labs. This culture not only encourages local innovation but also nurtures the skills necessary for sustainable technological engagement (Tsapi et al., 2024).

Addressing these challenges is crucial for the successful establishment and sustainability of Fab Labs and digital manufacturing spaces, which hold the potential to empower communities through skills development and collaborative innovation. Fab Labs not only foster technical skills

acquisition but also provide an interdisciplinary pedagogical model that can serve as a viable alternative to traditional education systems (Vieira et al., 2017).
In response to these challenges, this study aims to develop a MCDM framework to strategically select digital manufacturing equipment, effectively navigating and overcoming the aforementioned obstacles.
Specifically, this research seeks to answer the following questions:

1. What criteria should be considered in the selection of digital manufacturing equipment in low-income settings?
2. How can an MCDM framework facilitate more informed decision-making in the procurement process?
3. What strategies can be employed to promote a sustainable maker culture within these communities?

By investigating these questions, this study contributes to the body of knowledge on technological entrepreneurship while providing practical insights for enhancing the operational capacity of digital manufacturing spaces in Cameroon and similar contexts. Ultimately, fostering digital entrepreneurship through strategic equipment selection can yield broader socio-economic benefits, driving innovation and resilience in low-income settings.

2. LITERATURE REVIEW

Fab Labs have evolved significantly, emerging as crucial actors in both research and community innovation. Rather than merely serving as spaces for prototyping or education, they function as infrastructures for applied, action-oriented research, aligning closely with local needs and contributing to global knowledge production (Coskun et al., 2025; González et al., 2024; Calvo Juarez et al., 2024; Nadal & Domínguez, 2023; Burdiles et al., 2022; Gerodimou et al., 2022; Cabrera et al., 2021). This transformation highlights the dynamic interplay between technology and community engagement, particularly in low-income settings, where Fab Labs can address socio-economic challenges by fostering innovation and skill development.
Core tools like 3D printers, laser cutters, and CNC milling machines remain essential (Tsapi et al., 2024), with their applications expanding to meet diverse needs. These tools enable rapid prototyping and intricate design creation, supporting educational initiatives that help youth acquire critical skills for the modern workforce (Carqueijó et al., 2025). The integration of newer technologies, such as 3D scanners, is further shaping digital manufacturing capabilities by facilitating reverse engineering and model modifications (Debnath et al., 2025). This evolution reflects a shift toward sophisticated and integrated processes, allowing Fab Labs to offer advanced capabilities (Savastano et al., 2023). However, the effective use of these technologies is hindered by a lack of essential skills and experience required for their design and operation.

Table 1: List the main equipment outages (Brun et al., 2018)

Equipment	Duration	Scope
Laser cutter	3 months	Worn out laser tube limited laser machine to engraving or cardboard cutting only.
Desktop CNC	11 months	Inability to replace the broken 3mm collet prevented use of the desktop CNC with a large range of end-mills including PCB milling.
Desktop CNC	24 months	Inability to use a 1/8 inch (3.175mm) milling tools. Still unresolved.
Large CNC	6 months	Difficulties organising suitable local suppliers for 1/4 inch milling tools. No collet for 3,4 and 6mm tools.
Oscilloscope	10 months	Difficulties finding suitable local providers delayed thecommissioning of this system.
Vinyl cutter	6 months	Blunt cutting tool inside these machines has not been replaced leading to lower quality cuts.
Print and cut	6 months	Blunt cutting tool inside these machines has not been replaced leading to lower quality cuts.

Digital fabrication technologies lower the barriers to entry for small businesses, enabling entrepreneurs to quickly create and test designs while iterating based on user feedback. The collaborative nature of these spaces fosters knowledge sharing and innovation, enhancing access to entrepreneurship within the community. Nevertheless, significant barriers persist, particularly in developing nations. Complex procurement processes, limited local suppliers, and the perception of high costs (illustrated in Table 1) hinder effective adoption. Addressing these challenges is essential to maximize the potential of digital manufacturing in driving entrepreneurship and supporting local innovation ecosystems. Furthermore, a strategic focus on sustainable operational models is necessary to ensure that these spaces thrive independently while contributing to social and economic benefits for both users and the local environment.

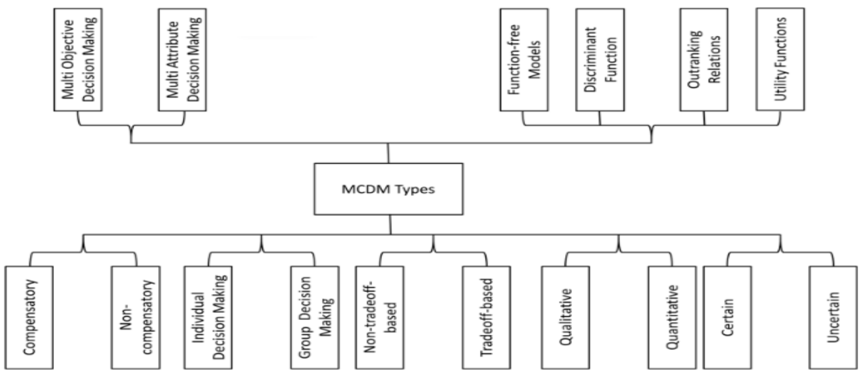

Figure 1. Different Classifications of MCDM (Taherdoost & Madanchian 2023).

Selecting appropriate equipment is a critical decision that influences the educational value and operational efficiency of maker spaces. The literature on digital technology acquisition indicates that such decisions involve conflicting criteria, including cost, technical performance, and usability. Previous studies have extensively applied different MCDM methods, see Figure 1, in various fields, such as manufacturing, construction, renewable energy technology, and medical device selection. For example, Bhatia & Williams (2023) utilized a hybrid MCDM approach to evaluate renewable energy solutions, integrating technical and ecological criteria. Similarly, Shbool et al. (2021) presented an MCDM framework for selecting medical devices, demonstrating the versatility of these applications across industries. Recent reviews emphasize the triple bottom line-economic, social, and environmental factors-in MCDM for equipment selection (Moretti et al., 2025).

Despite these advancements, there is a significant gap in applying structured, stakeholder-centric MCDM frameworks tailored to the unique ecosystem of digital manufacturing in low-income settings. Many digital fabrication spaces operate at the intersection of education, innovation, and community engagement, necessitating that their equipment selection criteria extend beyond traditional technical specifications. Important factors include pedagogical value, safety for novice users, and ongoing maintenance support. Frameworks that incorporate stakeholder perspectives are essential to align equipment selection with educational goals and community needs. In this context, Lamrani Alaoui et al. (2024) proposed a hybrid-fuzzy decision-making framework for digital technology selection, which could enhance MCDM processes in Fab Labs.

Additionally, the specific context of Fab Labs requires a nuanced understanding of user experiences and collaborative practices. Collaborative environments within digital manufacturing spaces have been shown to enhance learning and innovation through knowledge exchange. This collaborative spirit, wherein individuals share values, knowledge, and equipment, is critical for the success and sustainability of these ecosystems. Stakeholder involvement in MCDM processes has proven to improve decision-making outcomes and foster community ownership. Including diverse perspectives in machine selection ensures that tools align with user needs and supports sustainable practices within maker spaces.

Furthermore, Wei (2025) proposed a hybrid MCDM framework for analyzing business development models, suggesting that similar strategies could benefit Fab Labs in their equipment assessments. Hodgett (2016) highlighted the importance of selecting appropriate MCDM methods tailored to specific decision problems in equipment selection.

While MCDM frameworks have been effectively utilized in various domains, there remains an urgent need to adapt these methodologies for the unique characteristics of equipment selection in low-income settings. Recent reviews indicate an increasing use of MCDM techniques and the emergence of decision-support tools tailored for machine selection in manufacturing and construction (Hagag, 2023). Future research should focus on developing a comprehensive, stakeholder-centric MCDM framework that embraces the complexities of equipment selection in innovative environments. Studies such as those by Sun et al. (2025) reveal the necessity of innovative MCDM frameworks for optimizing diverse applications, emphasizing the potential for tailored approaches within digital manufacturing' unique ecosystems. This research addresses existing gaps by synthesizing decision criteria from operations management and engineering literature with practical needs identified by digital manufacturing stakeholders. The goal is to formalize equipment selection processes, making them more objective, justifiable, and aligned with the strategic goals of digital manufacturing spaces.

3. MATERIALS AND METHODS

This study was conducted in Bamenda, Northwest region of Cameroon. It employs a systematic and comprehensive approach to develop a MCDM framework specifically designed to optimize the selection of equipment for fab labs (Äkräs et al., 2022; Sun et al., 2025). The methodology integrates theoretical foundations, stakeholder feedback, and analytical modeling techniques to ensure that the framework is relevant, valid, and effective in the unique context of these fab labs. The research methodology is organized into four distinct phases:

Stakeholders engagement: Key stakeholders, including fab lab managers, educators, and students, are identified and engaged to gather insights into their needs, priorities, and constraints regarding equipment selection. Engagement methods, primarily interviews, are employed to ensure that the framework aligns with their requirements. Engaging with a diverse group of stakeholders allows for the identification of existing barriers and opportunities related to promoting a maker culture. Feedback from community members can reveal what resources, support systems, and cultural aspects are necessary for fostering an environment that encourages innovation and collaboration.

Identification and categorization of decision criteria: Drawing from stakeholder input, a comprehensive literature review, and sustainability principles, relevant factors influencing equipment selection are identified and categorized. The criteria are structured to encompass both quantitative and qualitative aspects. Stakeholders engagement ensures that the criteria for equipment selection are grounded in real-world experiences and challenges faced by users in low-income settings. This thorough identification process provides a robust foundation for understanding the diverse factors that should be considered in equipment selection, tailored specifically to the context of Fab Labs in low-income environments.

Selection of an appropriate MCDM technique: Existing MCDM techniques are reviewed to recommend a suitable method based on the type of data available, the preferences of decision-makers, and the requirements for robustness and sensitivity analysis. By reviewing various MCDM techniques and choosing one that suits the data availability and decision-makers' needs, the methodology ensures that the framework is capable of processing complex information effectively. This selection process empowers decision-makers by allowing them to evaluate multiple criteria simultaneously, leading to more sophisticated and informed procurement choices.

MCDM framework construction: This phase involves constructing the MCDM framework by integrating the selected MCDM technique with the identified criteria and alternatives. The integration of chosen criteria and MCDM techniques into a coherent framework allows for structured decision-making processes. This facilitates clarity in evaluating alternatives and promotes confidence in procurement decisions.

Each phase is designed to promote transparency, impartiality, and methodological rigor, ensuring the MCDM framework reflects both theoretical insights and community engagement. In alignment with the aspirations for sustainable technological innovation in low-income educational settings.

4. RESULTS

The proposed MCDM framework for fab lab equipment selection is illustrated in Figure 1 and consists of three main steps: problem structuring, selection of an appropriate MCDM technique, and decision reporting (Figure 2). This structured approach is specifically designed to address key questions regarding equipment selection criteria, informed decision-making, and strategies for promoting a sustainable maker culture in low-income settings.

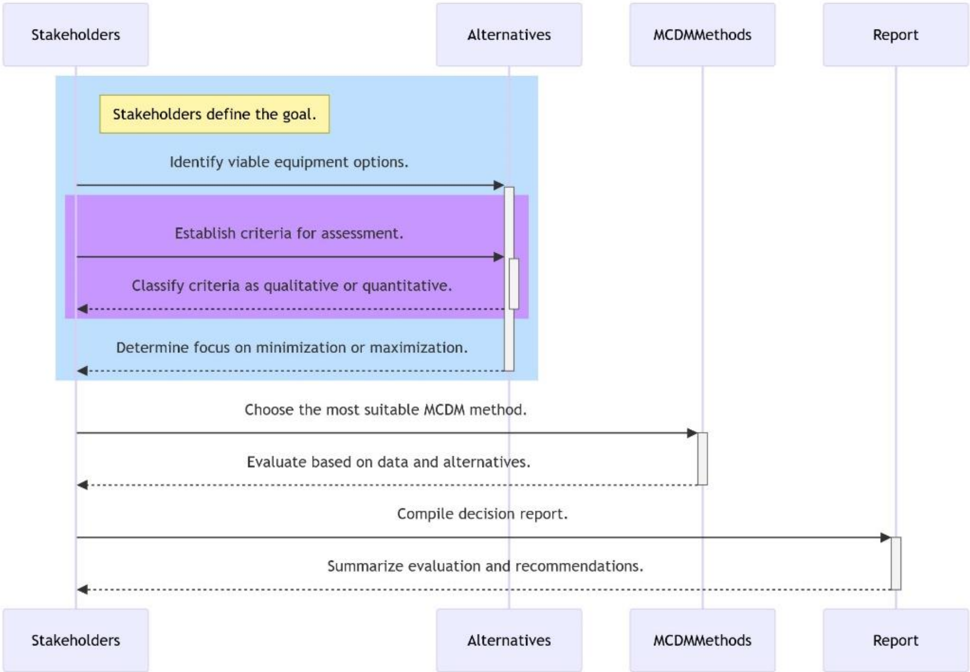

Figure 2. Proposed system model for Fab lab equipment selection.

In the initial step, problem structuring, decision-makers are required to clearly define the goal of the equipment selection process. They must identify a set of viable alternatives (equipment options) and establish a comprehensive set of relevant criteria that consider both qualitative and quantitative factors must be established. Stakeholder engagement plays a crucial role here, as input from technological entrepreneurs, educators, and users will help identify unique local needs. Criteria identified after interviewing some technological entrepreneurs include:

- *Procurement:* Accessibility and efficiency of the procurement process, including the availability of suppliers, lead times for acquisition.
- *Performance*: The capability of the equipment to meet user needs and project demands.
- *Reliability:* Longevity and maintenance requirements of the equipment.
- *Energy consumption:* Efficiency in power usage, crucial for sustainability.
- *Community impact:* The potential of the equipment to support skills development and foster local innovation.

Decision-makers must classify each criterion as either qualitative (e.g., ease of use, community relevance) or quantitative (e.g., costs, energy consumption). Additionally, they need to determine whether the focus for each criterion is on minimization (e.g., costs, energy consumption) or maximization (e.g., performance, reliability), ensuring that the framework aligns with the specific procurement goals of the Fab Lab.

The second step involves choosing the most suitable MCDM method that aligns with the specific nature of the decision problem. Factors to consider in this selection include

- *Data availability*: The type and precision of data available for each criterion. This is crucial for ensuring the robustness of the decision-making process.
- *Number of alternatives and criteria*: The complexity of the decision problem will influence the choice of technique.
- *Need for robustness and sensitivity analysis*: It is vital to select a method that can effectively handle variations in input data and provide reliable outcomes.

Techniques such as Analytic Hierarchy Process (AHP), Fuzzy AHP, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), or compromise solutions VIKOR may be evaluated based on these criteria. This strategic selection enables more informed decision-making by providing clarity on how each MCDM method handles the specific challenges associated with Fab Lab equipment selection and procurement in low-income settings.

The final step is the compilation of a decision report that summarizes the evaluation and ranking of the selected equipment. This report includes:

- *Detailed Analysis*: A thorough breakdown of the analysis conducted, emphasizing how the criteria were applied using the selected MCDM technique.
- *Rationale behind chosen method*: An explanation of why the chosen MCDM technique was deemed appropriate based on stakeholder input and contextual needs.

- *Results of the MCDM analysis*: A clear presentation of the rankings and evaluations of the equipment options, which reflects the needs and priorities identified in the problem structuring phase.
- *Recommendations*: Strategic recommendations for the equipment to be acquired, aimed at optimizing operational efficiency and fostering community engagement.

The decision report serves as a comprehensive document that communicates the selection process to stakeholders, facilitating informed decision-making. Additionally, this report can highlight strategies for promoting a sustainable maker culture, such as community workshops, training sessions on new technologies, and engaging local entrepreneurs in Fab Lab activities. By fostering collaboration and continuous feedback within these processes, the framework supports the development of a vibrant maker culture that aligns with community goals and encourages innovation.

5. DISCUSSION

The proposed framework for Fab Lab equipment selection provides a structured and systematic approach specifically designed to optimize the decision-making process in resource-constrained settings. It recognizes that equipment selection involves multiple conflicting criteria and requires a systematic evaluation process. Defining clear goals is essential to outline the specifications and functionalities needed for the new machine. Engaging stakeholders in developing the evaluation criteria and alternatives ensures that the selection process promotes transparency, facilitates effective collaboration, and enhances fundraising efforts in low-income settings. This approach aligns the equipment with community needs while fostering broader support for the initiative. These findings align with research on machine selection, which shows that stakeholder engagement significantly influences the decision-making process (Sun et al., 2025; Hagag et al., 2023; Hodgett, 2016).

Various Multi-Criteria Decision-Making (MCDM) methods have been employed in the selection of manufacturing machines, including 3D printers, CNC machines, and laser cutting systems. Notable methods include Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), DEMATEL combined with Entropy and VIKOR, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and several hybrid approaches (Avramova et al., 2025).

For instance, Complex Proportional Assessment (COPRAS) and Operational Competitiveness Ratings Analysis (OCRA) were utilized to select the most appropriate laser cutting system (Madić & Radovanović, 2021). Additionally, a hybrid fuzzy AHP and PROMETHEE approach was proposed for selecting a suitable 3D printer (Çetĩnkaya et al., 2017), while fuzzy AHP combined with TOPSIS was suggested to guide 3D printer selection (Ransikarbum & Khamhong, 2021). A fuzzy AHP method was also recommended for selecting a 5-axis CNC machine (Cioca et al., 2019). Using a case study of seven alternative CNC machines, four main criteria and thirteen sub-criteria, the MCDM methods GRA, COPRAS, and MULTI-MOORA were employed to rank the alternatives (Sahin & Aydemir, 2022). It is recommended that addressing the same MCDM problem using multiple methods can yield more reliable outcomes, enabling analysis and comparisons across results. Relying on a single method may lead to poor decision-making in machine selection (Hagag et al., 2023).

The final step, decision reporting, serves as a crucial mechanism for promoting transparency and collaboration among stakeholders. By compiling a comprehensive decision report that details the evaluation process, the rationale behind the chosen methods, and the final recommendations, the framework fosters a culture of openness that engages the community. This report can also include strategies for enhancing the maker culture, such as:

- *Community Workshops*: Organizing training sessions and workshops that empower users to learn about equipment operation and maintenance, ensuring that the community can effectively utilize the resources available.
- *Engagement with Local Entrepreneurs*: Collaborating with local businesses to showcase the capabilities developed within the Fab Lab, encouraging entrepreneurial activities and innovation.
- *Continuous Feedback Loops*: Establishing mechanisms for ongoing stakeholder feedback fosters a culture of adaptability and responsiveness, ensuring that the Fab Lab evolves with community needs.

6. CONCLUSION

This study contributes a comprehensive MCDM framework for the selection of digital manufacturing equipment, emphasizing a structured approach that significantly enhances decision-making processes. By offering a systematic pathway to navigate the complexities of equipment selection, the framework ensures alignment with the specific needs of the community. The integration of thorough evaluations with stakeholder engagement not only improves the effectiveness and reliability of the selection process but also fosters a collaborative environment essential for fostering innovation.

Looking forward, future research should explore the application of this framework across diverse contexts to further validate its effectiveness and adaptability. Areas for investigation could include different regional settings, varying community needs, and alternative technological contexts to ascertain the framework's versatility. Additionally, practical applications of the findings could include the development of training programs that equip local stakeholders with the skills necessary to utilize the framework effectively.

Moreover, this MCDM framework supports the cultivation of a vibrant maker culture that aligns with community goals, encouraging ongoing engagement and collaboration. This holistic approach not only enhances operational efficiency within Fab Labs and digital manufacturing ecosystems, but also strengthens the socio-economic fabric of low-income communities, positioning these spaces as critical hubs for technological entrepreneurship.

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