

# Deployment of Concept Design and Fabrication for Flood Rescue Boat Ladder

Muhammad Nur Iman Mohamad Yusof<sup>1</sup>, Helmy Mustafa El Bakri<sup>2\*</sup>

<sup>1</sup> Department of Mechanical Engineering Technology, Faculty of Engineering Technology,  
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

\*Corresponding Author: [helmym@uthm.edu.my](mailto:helmym@uthm.edu.my)

DOI: <https://doi.org/10.30880/peat.2025.06.02.036>

## Article Info

Received: 26 June 2025

Accepted: 11 August 2025

Available online: 30 October 2025

## Keywords

Flood rescue, boat ladder, morphological analysis, 3D printing, emergency design

## Abstract

Flood disasters in Malaysia frequently challenge rescue teams during the extraction of victims, especially during boarding operations. This project presents the design and development of a flood rescue boat ladder aimed at enhancing safety and efficiency in flood emergencies. A survey conducted with the Fire and Rescue Department (JBPM) Pagoh provided key insights for the design requirements. Several design concepts were generated and evaluated using morphological analysis and the Pugh Controlled Convergence (PuCC) method. A scaled down prototype of the top rated design concept was developed using 3D printing with Polylactic Acid (PLA) material. The final design incorporated features for multifunctional use as a ladder, ramp, or bridge, addressing critical concerns such as portability, quick deployment, and user safety.

## 1. Introduction

Floods are one of the most frequent and severe natural disasters in Malaysia, particularly during the northeast monsoon season. These events result in significant damage to communities, infrastructure, and public safety. Malaysia's geographical location near the equator, combined with inadequate drainage systems and rapid urban development, contributes to frequent flooding during heavy rainfall (Sinar Harian, 2024). To manage such disasters, agencies like the National Disaster Management Agency (NADMA) and the Fire and Rescue Department of Malaysia (JBPM) play vital roles in coordinating emergency response and rescue operations. Since the issuance of Arahan No. 20 by the Majlis Keselamatan Negara (MKN) in 1997, disaster response has become more structured and collaborative (MKN, 1997). One of the essential tools used during these operations is the rescue boat ladder, which enables rescuers to assist victims safely onto boats during evacuation.

During flood rescue operations, one of the critical challenges faced by rescue teams is the difficulty victims experience when climbing into the rescue boat, especially elderly individuals, children, or those with injuries. In many cases, rescuers are forced to lift victims manually, which is physically demanding and increases the risk of injury for both parties. Current boat ladder solutions are often unsuitable for unstable, fast-moving water conditions, lacking features such as quick deployment, stability, and adaptability. This highlights the need for a boat ladder specifically designed for flood situation. There is limited research that evaluates or optimizes ladders specifically for flood rescue purposes. This gap needs to be addressed to enhance safety, reduce rescue time, and support efficient operations in high-risk conditions.

This study aims to improve flood rescue operations by developing a better boat ladder design suited to real-world flood conditions. The first objective is to identify the most effective concept design for a flood rescue boat ladder by collecting practical input from JBPM officers and analyzing past patents and commercial products. The second objective is to develop and test a 70% scaled prototype using 3D printing to validate the ladder's

performance in terms of safety, portability, and deployment efficiency. Through tools such as the Black Box model, Morphological Analysis, and the Pugh Controlled Convergence (PuCC) method, this research aims to generate, evaluate, and refine ladder designs (Álvarez & Ritchey, 2015; Dragomir et al., 2016). The outcomes are expected to contribute to more effective rescue equipment that supports safer and faster flood response in Malaysia.

## 2. Methodology

This chapter presents the methodology used in designing and developing a flood rescue boat ladder prototype aimed at improving safety and efficiency during emergency operations, as shown in Figure 1. The process began with data collection through surveys and interviews conducted with officers from the Fire and Rescue Department (JBPM) Pagoh to gather insights on the criteria needed to place in the prototype. Based on this input, design requirements were established, and several concept ideas were generated using tools such as the black box model and morphological analysis. The concepts were then evaluated using the Pugh Controlled Convergence (PuCC) method to select the most suitable design. A detailed CAD model of the chosen design was created, followed by the fabrication of a 70% scale prototype using 3D printing technology with PLA material. The prototype was then tested in a controlled environment to assess its functionality, usability, and overall performance.

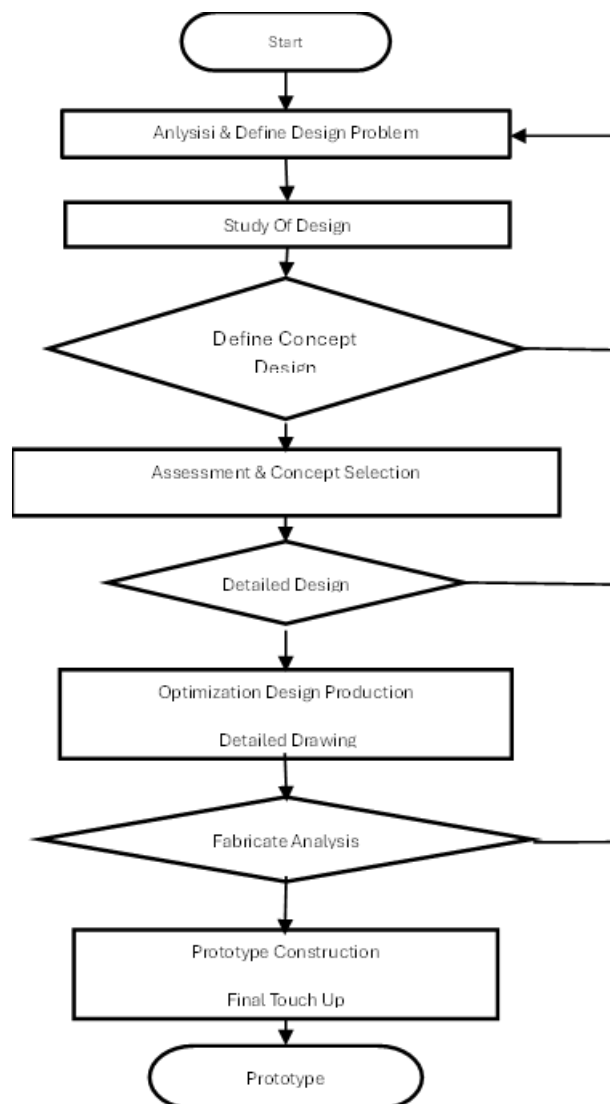


Figure 1: Project flowchart

### 2.1. Data Collection

The methodology began with the collection of qualitative data through interviews and surveys with officers from the Fire and Rescue Department of Malaysia (JBPM) Pagoh. These sessions were conducted to gather firsthand information about the limitations and challenges associated with existing boat ladder designs during flood rescues. Two sets of questionnaires were distributed. The first aimed to understand the overall experiences and challenges faced by rescuers during flood operations, while the second focused on assessing the importance of specific design criteria such as safety, stability, and ease of deployment. This feedback provided the foundation for identifying key design requirements.

### 2.2. Functional Analysis Using the Black Box Model

To structure the initial concept development, the Black Box model was used to define the key functions of the flood rescue boat ladder, as shown in Figure 2. This model focused on three main components: input, function, and output. Inputs included rescuers and victims needing access to the boat; functions involved safe, stable climbing and ease of use; and outputs targeted successful boarding during flood rescues. This model helped ensure all critical design functions were considered at an early stage. Criteria Weightage and Concept Evaluation

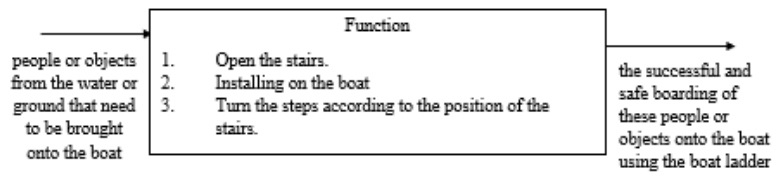




Figure 2 : How the input, output, and several functions for the flood rescue boat ladder

### 2.3. Concept Generation with Morphological Analysis

Table 1: Morphology chart for flood rescue boat ladder

Sub function	1	2	3	4	5
A Installation ladder in the boat	U hanger	clamp	Install permanently	Using a carabiner	Socket
B Storage	Foldable ladder	Telescopic	Foldable frame	Roll	hanging
C Step grip	Pattern on the stairs	Use rubber			
D Stability of the ladder	Butt to the ground	Back Support	Strong beam		

E Angle of the ladder	Adjustable angle 	Rigid 			
--------------------------	---	--	--	--	--

Once the key functions were identified, a morphological chart was developed to explore a wide range of design alternatives systematically. Table 1 shows that the boat ladder is divided into subcomponents, such as attachment mechanism, folding structure, step grip material, and ladder angle. For each subcomponent, multiple variations were proposed. The collar line shown in Table 1 is the combination of different features from each category; a large number of conceptual designs could be generated. This method allowed for creativity while maintaining a structured and logic-based design process (Zwicky, 1962; Álvarez & Ritchey, 2015).

### 2.4. Evaluation of Design Concepts

The second phase involved generating and evaluating multiple design concepts using the Morphological Chart method. Each concept was formed by combining various options for sub-functions, such as attachment mechanism, storage design, grip type, and angle control. To select the best design, the Pugh Controlled Convergence (PuCC) method was applied. Ten key evaluation criteria—identified through the second round of surveys were weighted using a 3-point scale, with scores reflecting levels of importance (1 = not important, 2 = important, 3 = very important). The criteria included: scope of use, target user compatibility, ergonomics, safety features, ease of deployment, material durability, lifespan, portability, compactness, and affordability.

Rank	Criterion	Average Rating (Weight)
1	Ergonomic Features	4.57
2	Versatility & Adaptability	4.38
3	Suitability for Flood Rescue	4.38
4	Cost-Effectiveness	4.33
5	Compact Storage	4.33
6	Size/Portability	4.29
7	Safety Features	4.24
8	Ease of Deployment	4.24
9	Material Quality	4.19
10	Longevity (10–15 years)	4.14

Figure 3 : Ranking and weightage of criteria

Each design was compared against a commercial benchmark using a decision matrix. Concepts were assigned scores of “+” (better), “S” (same), or “-” (worse) for each criterion. The concept with the highest sum total was selected for prototyping. Figure 3 and Table 2 provide a visual summary of this decision process, showing how the chosen design met critical needs, particularly in terms of quick setup, foldability, and user safety.

### 2.5. Concept Selection Using the PuCC Method

After generating several concepts, the Pugh Controlled Convergence (PuCC) method was used to evaluate and select the most viable design. Each concept was compared against a benchmark (datum) using a decision matrix. Evaluation criteria, such as durability, safety, portability, cost, and ease of deployment, were weighted based on their importance, which was determined from survey results shown at Table 2. Each design option was rated using symbols (+ for better, - for worse, and S for same), and the concept with the highest overall score was selected. This iterative and comparative approach helped ensure a data-driven and balanced selection (Khan & Smith, 1989).

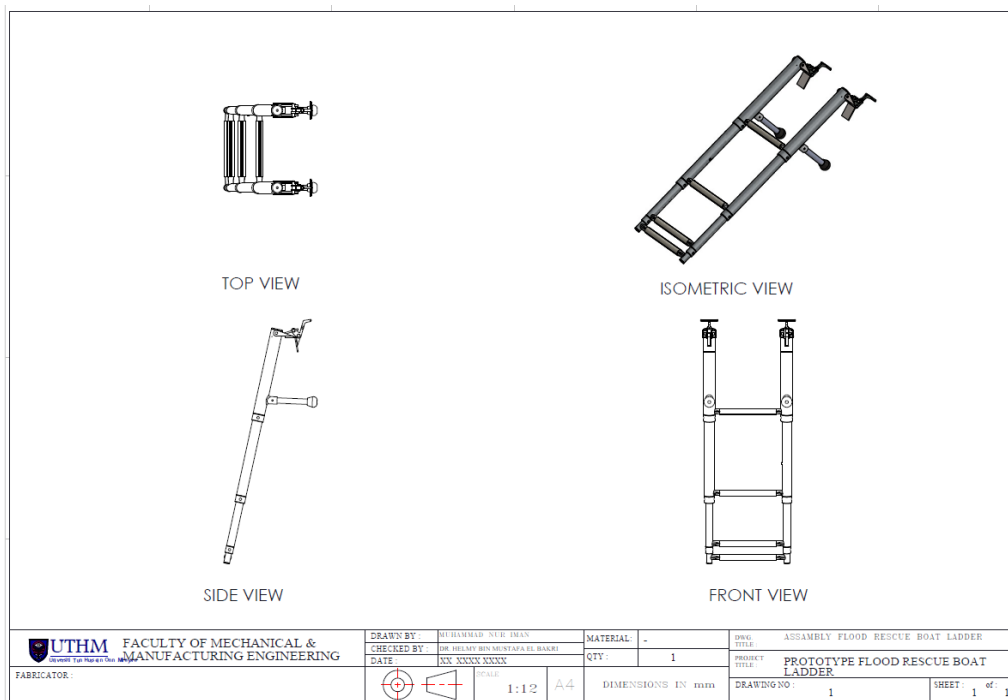
### 2.6. Detail Drawing

After selecting the final concept, a detailed design was created using SolidWorks software. The drawings included precise dimensions, materials, tolerances, and annotations. These detailed illustrations were critical for

ensuring that the prototype components could be fabricated accurately and assembled correctly. Figure 4 from the project shows a close-up of the clamp arm design created in SolidWorks, which includes the joint structure, mounting hole locations, and rib reinforcement for strength. Detail drawings served as the technical foundation for 3D modeling and later prototype assembly, ensuring consistency and manufacturability throughout the project.

**Table 2**  
**: Pugh Controlled Convergence (PuCC) Evaluation**

Criteria	Criteria Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
1 Scope	3		+	-	+	-
2 Target Users	3			-	-	-
3 Ergonomic Considerations	3	D	+	-	+	-
4 Safety Features	2	A	+	S	-	-
5 Ease of Deployment	1	T	S	S	+	-
6 Durability And Material Quality	1	U	S	S	S	S
7 Lifespan	1	M	S	+	S	-
8 Size and Portability of The Ladder	2		S	-	-	+
9 Compact and Easy to Store	2		S	+	-	+
10 Affordable and Cost-effective	2		+	-	-	S
Total +			5	2	3	2
Total -			0	5	5	8
Sum Total			5	-3	-2	-6
Actual Total			13	-10	-4	-9



**Figure 4 : Drawing assembly prototype flood rescue boat ladder**

## 2.7. Prototype Fabrication

The selected design was modeled in SolidWorks and exported as an STL file. A 70% scale prototype was printed using PLA material on the Ultimaker 3 Extender. 3D printing was chosen for its speed, cost-effectiveness, and ability to produce complex geometries. Before printing, the model was sliced using Cura software, which generated the G-code required by the printer. Once printed, the parts were cleaned, support material was removed, and the components were assembled. This allowed for real-world evaluation of structural stability, ergonomics, and feature usability. The prototype served as a proof of concept, allowing for testing and refinement before potential full-scale production.

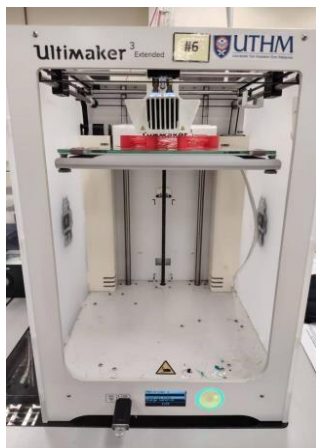


Figure 5 : 3D Printing using Ultimaker 3 Extender

## 3. Result

This chapter presents the results of the surveys and questionnaires conducted to determine the most suitable project title and to assess the importance of various design criteria. The collected data reflects the preferences and perspectives of respondents, offering valuable insights into key themes relevant to the target audience. In the latter part of the chapter, five selected design concepts are introduced for further evaluation, serving as potential solutions to guide the development of the prototype.

### 3.1 Survey and Interview Findings

The initial phase of the study involved collecting data from JBPM Pagoh personnel through interviews and structured questionnaires. The majority of respondents had extensive experience in disaster management, particularly in flood situations. Their feedback identified key operational issues, such as difficulties boarding rescue boats in high water levels, the instability of standard ladders, and the time delay caused by complicated deployment mechanisms.

### 3.2 Design Drawing

A detailed design drawing was created to represent the flood rescue boat ladder before prototyping visually. This drawing served as a blueprint, developed using SolidWorks CAD software. The purpose of the design drawing was to ensure manufacturing accuracy, alignment between components, and clarity during the 3D printing and post-processing stages.

The main structure of the ladder consisted of interconnected rungs supported by a foldable frame. Special attention was given to ergonomic considerations, including step width and spacing, grip texture, and the overall angle of inclination. Key components such as the clamp attachment, folding mechanism, and angled support legs were included in the detailed part views. These drawings also included exploded views to demonstrate assembly steps

### 3.3 Prototype Fabrication and Assembly

Once the final design was selected, a 70% scale prototype was produced using 3D printing with PLA material. The CAD model was developed in SolidWorks, converted into STL format, and processed in Cura slicing software before being printed on an Ultimaker 3 Extender. The prototype consisted of several modular parts, including the clamp, ladder rungs, support frame, and grip surfaces. Post-processing involved removing support structures and sanding edges for a smooth assembly. As shown in Figure 6, the parts were successfully assembled and matched the intended design specifications.

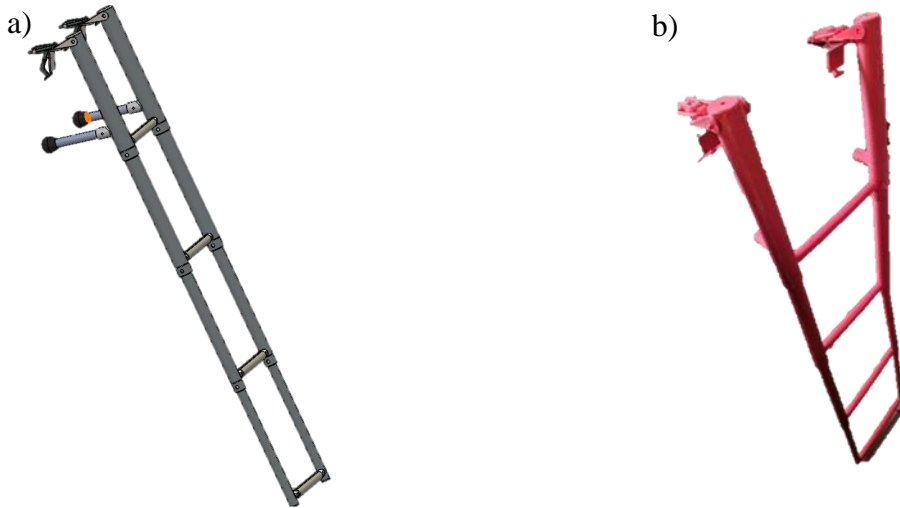


Figure 6 : a) 3D design of the prototype b) prototype using 3D printing

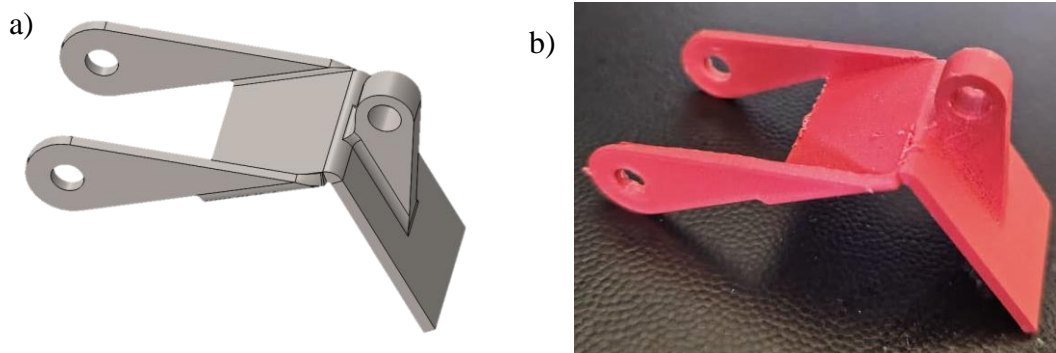
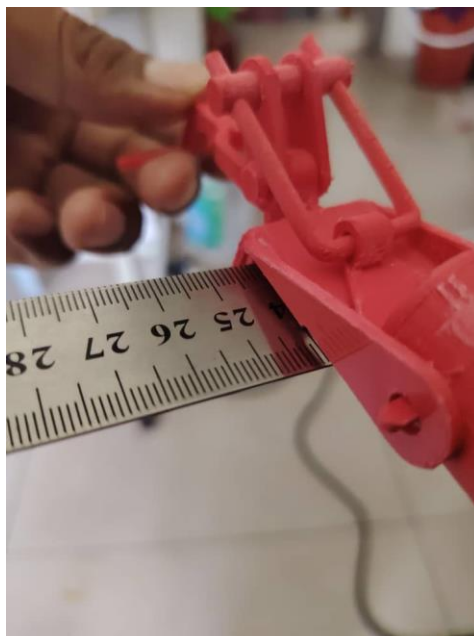


Figure 7 : a) 3D design of base part of the prototype b) base part prototype using 3D printing

Testing of the assembled prototype focused on evaluating core performance aspects such as portability, stability, and multi-functionality. The ladder could be easily deployed. Its adjustable-angle design allowed it to serve multiple roles: as a vertical ladder, a horizontal ramp, or a small bridge. The structure remained stable when leaned against flat and curved surfaces, simulating conditions like boat walls and uneven terrain. While full-scale material testing was not within the project scope, the PLA model effectively demonstrated the design's functional logic, ease of use, and potential to enhance flood rescue operations.



**Figure 8 : Testing the clamp**

### **3.4 Limitations and Recommendations for Future Studies**

The development of the prototype in this study was intended primarily for the purpose of evaluating basic functionality and component integration, rather than for immediate field deployment. The prototype was fabricated using PLA material via 3D printing, which allowed for efficient and cost-effective testing of form, fit, and basic function. This approach enabled the research team to assess the interaction between parts, folding mechanisms, and the overall usability of the design in a controlled environment. However, the prototype was not designed to withstand the loads, environmental conditions, or physical stress typical of real flood rescue operations. Therefore, it serves as proof of concept to verify whether the fundamental design logic is valid before proceeding to full-scale development using appropriate engineering materials. Future efforts should focus on upgrading to full-size models with stronger materials and conducting extensive real-world testing to ensure safety and performance in operational conditions. Future studies should focus on full-scale prototyping using appropriate engineering materials and conduct field testing with trained rescue personnel. Long-term durability tests, including corrosion and load stress tests, are also recommended. Additionally, integrating IoT features such as position tracking or deployment sensors could enhance rescue coordination in large-scale flood events.

## **4. Conclusion**

This study successfully developed a flood rescue boat ladder design that addresses the limitations of existing systems by incorporating user feedback from JBPM Pagoh and applying systematic design tools such as the Black Box model, Morphological Chart, and the Pugh Controlled Convergence (PuCC) method. The selected concept prioritized safety, quick deployment, and multifunctionality, and a scaled-down prototype was successfully produced using 3D printing. Although the prototype was limited in scale and material strength, it met the core design objectives and demonstrated its potential as a practical tool for flood rescue operations. Future development should focus on full-scale production, real-condition testing, and material enhancement to improve its readiness and reliability for emergency response.

## **Acknowledgement**

The author would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, for its support.

## References

- [1] Álvarez, A., & Ritchey, T. (2015). *Applications of General Morphological Analysis: From Engineering Design to Policy Analysis*. *Acta Morphologica Generalis*, 4(1), 1–40.
- [2] Dragomir, C., Alboaie, L., & Maftei, M. (2016). *Concept Selection Using Pugh Controlled Convergence Method*. *Scientific Bulletin of Naval Academy*, 19(2), 361–366.
- [3] JBPM Pagoh. (2024). *Flood Rescue Operations Survey and Interview Responses*. Unpublished internal report.
- [4] Khan, M. S., & Smith, G. F. (1989). *A methodology for evaluating design alternatives using weighted decision matrix*. *Journal of Engineering Design*, 1(2), 131–143.
- [5] Majlis Keselamatan Negara (MKN). (1997). *Arahan MKN No. 20: Dasar dan Mekanisme Pengurusan Bencana Negara*. Jabatan Perdana Menteri, Malaysia.
- [6] Sinar Harian. (2024). *Malaysia's Flood Risk Rises Due to Urbanization and Rainfall*. Retrieved from <https://www.sinarharian.com.my/>
- [7] Hariyono, S., Sugeng, B., & Hartono, H. (2022). *Design Analysis of Aluminum Ladder for River Rescue Boat*. *Journal of Mechanical Systems*, 14(3), 22–29.
- [8] Samsul Huda, M., Anuar, M. K., & Fikri, M. A. (2023). *Evaluation of Foldable Ladder Mechanisms for Emergency Use*. *International Journal of Disaster Equipment Engineering*, 5(1), 45–52.