

CONCEPTUAL DESIGN OF AN IMPROVED KAYAK RACK

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ABSTRACT

This study discusses the conceptual design process of an improved kayak rack. Observations at UiTM Cawangan Terengganu Kampus Bukit Besi indicate that students have had difficulty storing kayaks due to the rack's height and weight. To solve the problem mentioned above, an alternative is proposed in the form of an improved conceptual kayak rack incorporating lifting motion. The methodologies employed for conceptual design consist of problem definition, concept generation, and concept selection. Through the integration of a lifting mechanism that improves the kayaks' accessibility, the removal and storage of kayaks from the rack is simplified for users. Moreover, ergonomic elements are integrated into the concept to maximize user comfort and reduce the likelihood of sustaining accidents. The outcome of this paper is the establishment of the final concept for the improved kayak rack. This concept will serve as the guidelines for the subsequent mechanical engineering design process, which includes embodiment design, detailed design, and prototyping.

Keywords: Kayak Rack, House of Quality, Morphological Method, Weighted Decision Matrix, Conceptual Design, Mechanical Engineering Design

1.0 INTRODUCTION

Kayak is one of the campus activities available to students and staff at UiTM Cawangan Terengganu Kampus Bukit Besi. This is because Tasik Puteri Lake is situated near the campus. The lake consists of 131 hectares in area, or approximately 0.1 km² [1]. For storage purposes, a designated rack is required to preserve the health of the kayak. Furthermore, this guarantees that the kayak avoids any elements that may cause it to deteriorate, such as direct sunlight or fungus growth caused by improper drying processes. In UiTM Cawangan Terengganu Kampus Bukit Besi, a dedicated kayak storage building is available near the lake. This facilitates the transportation of kayaks from the campus to the lake and back again for the benefit of the students and staff. Figure 1 shows an existing kayak storage building on the campus. The rack consists of three shelves made of steel frame, which currently can hold up to six kayaks at one time. However, the current kayak racks system needs more efficiency in terms of kayak utilization. This is primarily due to the fixed rack and the increased energy required to lower a kayak from a higher level, which could be more efficient for storage purposes. In UiTM Cawangan Terengganu Kampus Bukit Besi, studies related to kayak application have been conducted recently [2, 3].

Outside UiTM Cawangan Terengganu Kampus Bukit Besi, studies related to kayak storage systems also have been done. One of the studies is the design and fabrication of a Public Locker for Non-Motorized Watercraft [4]. The watercraft is secured at both bow and stern by an adjustable locking system that also incorporates a compact locker for storing paddles and life jackets, all secured with a single user-supplied padlock. Besides that, research on the development of automated roof kayak systems, with a focus on designing, building, and testing a modular automatic roof rack that simplifies lifting, positioning, and securing paddle crafts on car roofs, has been done [5]. These studies aimed to provide customers with an automated alternative to the manual loading process, ultimately enhancing convenience and ease of use. However, studies on the effectiveness of existing kayak racks on the campus and studies related to improvement of fixed kayak rack have yet to be conducted.

Therefore, this paper focused on an improved kayak rack to facilitate its use. The conceptual design stage in the mechanical engineering design process is utilized. This includes the problem definition, concept generation, and concept selection process. In the end, an optimum conceptual design for an improved kayak rack is chosen and finalized.

2.0 METHODOLOGY

This section highlights the methodologies employed during the conceptual design stage for the improved kayak rack designs. The conceptual design stage in the mechanical engineering design process is utilized. This includes the problem definition, concept generation, and concept selection process. In the end, an optimum conceptual design for an improved kayak rack is finalized.



Figure 1: Kayak Storage available in UiTM Cawangan Terengganu Kampus Bukit Besi

2.1 Problem Definition

The studies started with observations and interviews with the staff and students regarding kayak storage activities on the campus. This is to ensure that genuine problems are determined and identified. This interview aims to collect primary information from individuals who have experience participating in campus kayak activities. The interview comprises three elements: (i) personal details, (ii) past experiences, and (iii) recommendations. Afterward, all the essential information is employed to determine the precise issue.

The initial section encompasses personal data, including age, gender, and height. The purpose of this is to guarantee that the data collected in sections (ii) and (iii) yield accurate and exact responses. This is to verify the precision of the received information's response. This study examines the participant's relationship and affiliation with the campus.

The second (ii) section aims to understand the kayak handling process better while exiting the kayak and participating in storage-related tasks. The following section discusses the prevalent challenges users face within the campus environment. The objective of the final (iii) sections is to collect user feedback and recommendations for possible improvements that can be integrated into the existing kayak rack systems to resolve the concerns outlined in section (ii). In addition, surveys have also been conducted to reach as many users as possible. The survey questions are analogous to the questions used in interview methodologies. The outcomes of the interviews and surveys are presented in Table 2.

Table 2 shows that 80% of the participants agree that lowering the kayak from the highest level of the kayak rack is challenging. Furthermore, 20% of the respondents affirm that engaging in the same activity results in an injury. As a result, 76.9% of the respondents support the establishment of an improved kayak rack in the kayak storage area. This demonstrates the need for a specially developed kayak rack focusing on user convenience. Thus, the identified problem related to the kayak rack is shown in Table 1 below.

Table 1: Problem-related to the existing Kayak Rack in UiTM Cawangan Terengganu Kampus Bukit Besi

No	Problem
1	The students and staff face challenges when it comes to storing the kayaks due to the inadequate ergonomic features of the storage racks.
2	The kayak racks' height is unsuitable for some of the users.
3	This lack of efficiency leads to time-consuming preparations for kayak activities.

Table 2: Outcome from the Interviews and Survey Activities

Question	Answer			
	Percentage (%)			
	Section A			
Staff or students of UiTM Bukit Besi	Student		Staff	
	94.1		5.9	
Gender	Male		Female	
	64.7		35.3	
Age	18-25 years old		26 and above	
	94.1		5.9	
Health condition	Good		Not good	
	100		0	
Height	Below 175 cm		175 and above	
	64.7		35.3	
	Section B			
Experience in kayak activity at UiTM Terengganu Campus Bukit Besi	Yes		No	
	11.8		88.2	
Experience in taking the kayak from the store outside the campus	Yes		No	
	18.8		81.3	
Problems, injuries, or difficulties faced when taking the kayak from the rack	Yes		No	
	6.2		93.8	
I felt tired when taking the kayak from the rack	Yes		No	
	21.4		78.6	
Taking the kayak from the highest level of the rack	Yes		No	
	12.5		87.5	
Experience when taking the kayak from the highest level	Easy and did not suffer injury.	Easy but suffer injury	Hard but did not suffer injury.	Hard and suffer injury
	0	0	80	20
Duration when taking the kayak	Below 5 minutes	Between 5- 10 minutes	Above 10 minutes	
	22.2	44.4	33.3	
			No	
			11.1	
Felt differences taking the kayak from the lowest level to the highest level of the rack	Yes			
	88.9			

Section C		
It needs a new rack	Yes 76.9	No 23.1
The rack that will be produced needs to provide more space when doing the process	Yes 85.7	No 14.3
Suggestion	Make it like a multi-story carpark but with a simple application (without a motor) Use gear, stairs, or other. Put more safety stuff. Optimal height. Shelves and storage areas should be positioned at heights that minimize awkward posture and overreaction.	

2.2 Customer Requirements

Based on the interview and survey, a compilation of customers' requirements is presented in Table 3 below. These requirements shape the final consumer's assessment of a product's quality [6]. Five customer requirements were identified: safety, usability and convenience, space efficiency, reliability, low maintenance, and time reduction for storage-related activities. These customer requirements subsequently be utilized in developing the House of Quality diagram.

Table 3: Identified Customer Requirement for an Improved Kayak Rack System

Customer Requirements	Description
Safety	The rack should be made of durable materials capable of securely holding the weight of stored items without collapsing or toppling over. It should include safety features like locking mechanisms to ensure user safety.
Usability and convenience	The rack should have an easy-to-use lifting mechanism and an intuitive interface. It should facilitate efficient identification and retrieval of items through labeling options and clear visibility. Ergonomics and comfort should be considered to promote good posture and minimize strain.
Space efficiency	The rack should maximize storage capacity while occupying minimal floor space. It should be configurable, allowing for height adjustments of shelves to accommodate different items.
Reliability and Low Maintenance	The rack should be constructed from premium materials, ensuring long-term reliability. It should require minimal maintenance due to its durable construction and lifting mechanism.
Time reduction	The rack should reduce the time needed for storage-related tasks. It should provide easy and quick access to stored items, eliminating the need to search multiple shelves or compartments. Lifting the rack should allow users to access different sections efficiently, improving overall efficiency.

2.3 Engineering Characteristics

Table 4 presents a comprehensive compilation of engineering attributes determined per the customer's desired outcome. Establishing the engineering characteristics is critical to writing the product design specification [6]. The engineering characteristics comprised eight aspects: load capacity, structural stability, durability and corrosion resistance, ease of installation and adjustment, compatibility and adaptability, user safety, material specifics, and maintenance and upkeep. These engineering characteristics will be used in the House of Quality diagram's development, which subsequently correlate with the customer's requirements. This is to determine which engineering characteristic and customer requirement is most critical for developing an improved kayak rack.

Table 4: Identified Engineering Characteristics for an Improved Kayak Rack System

Engineering Characteristics	Description
Load Capacity	The maximum weight the rack can securely support
Structural Stability	Ability to withstand loads and environmental conditions without deforming or failing
Durability and Corrosion	Resistance to outdoor elements and long-term durability
Ease of Installation and Adjustment	Convenience and simplicity of the installation and adjustment process
Compatibility and Adaptability	Ability to accommodate various vehicle types, kayak sizes, and configurations
User Safety	Measures to ensure the kayak remains stable during transportation
Material Details	Selection of high-quality materials with appropriate properties
Maintenance and Upkeep	Design features that facilitate easy cleaning, inspection, and maintenance

2.4 House of Quality

The House of Quality (HOQ) is a tool derived from Quality Function Deployment. It establishes design boundaries, depicts the correlation between respondent needs and the matrix for meeting those needs, and highlights the design team's emphasis on producing high-quality products [6]. The HOQ is established for this study to determine the important factors related to customer requirements and engineering characteristics that need to be considered when developing the concept for an improved kayak rack.

Based on the HOQ table, the customer gives the highest weightage, resulting in 26% of the total, to ergonomic factors, compared to time and space reductions, reliability, and safety. An ergonomically enhanced kayak rack can reduce the user's fatigue and health issues. Regarding engineering characteristics, the rack kayak's size and ease of operation receive a weightage of 30% in importance. This is compared to the same factor's weight, production cost, and durability. Therefore, the Product Design Specification (PDS) table emphasizes the following factors: production, lifetime, and durability.

Table 5: House of Quality for an Improved Kayak Rack System

Relative Weighth	Customer Importance	Category	Customer Requirements	Functional Requirements						Product A	Product B
				Direction of Improvement							
				▲	▼	▲	▼	▲	▲		
			Weight	Cost of Production	Expected Lifetime	Dimension	Useability	Durability			
16%	3	Feature	Safety	9		1		9	3	4	2
16%	3	Specification	Reliable		9	9		3	9	4	4
26%	5	Specification	Ergonomics				9	9		5	1
21%	4	Feature	Time Saver				9	9		4	1
21%	4	Feature	Space Saver		9		9			4	1
Importance Rating Sum				144	333	160	612	615	192		
Relative Weight				7%	16%	8%	30%	30%	9%		

2.5 Product Design Specifications

The Product Design Specification (PDS), presented in Table 6, describes the characteristics and requirements that define the product undergoing design. It is an essential part of the product development process [7]. The PDS highlights the parameters used in the development of the rack. There are 17 parameters used in the PDS. These specifications are later used as the guidelines for generating and selecting the final concepts of an improved kayak rack.

3.0 RESULT AND DISCUSSION

3.1 Physical Decomposition

As seen in Figure 2, physical decomposition involves directly segregating the product or subassembly into its parts and secondary subassemblies, with a precise description of how these elements are interconnected to generate the product's behaviors [8]. It was found that the physical decomposition of a kayak rack consists of three main components: the holder, structure, and lifting elements. The outcome of this diagram is that functional decomposition is produced to identify what functions exist in that product.

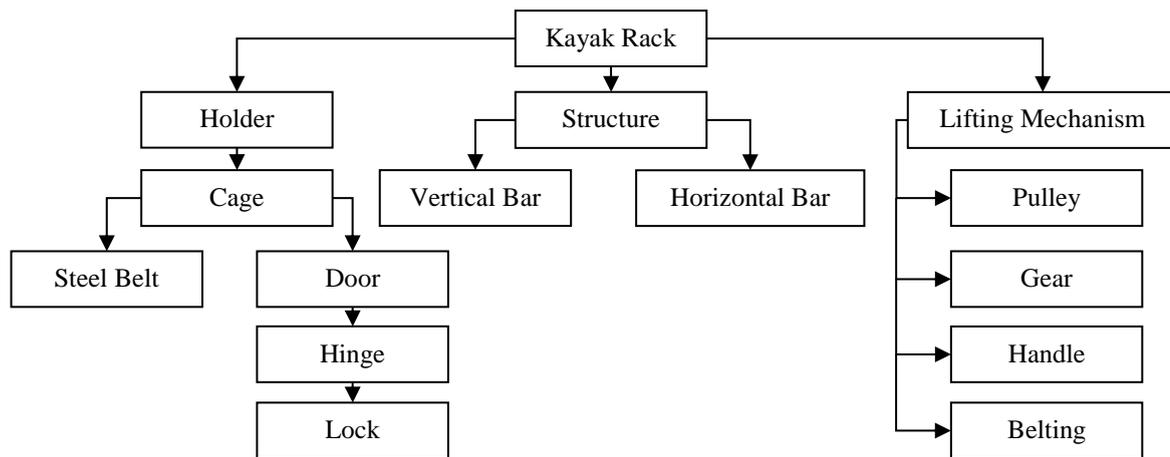


Figure 2: Physical Decomposition of an Improved Kayak Rack Systems

Table 6: Product Design Specification for an Improved Kayak Rack System

No	Parameter	Description
1	Performance	The rack helps make the process of taking the kayak easier Neat
2	Environment	Save space Safe to take canoe
3	Life Expectancy	More than five years if the maintenance processes are being followed. Monthly
4	Maintenance	Chain must be added chain lube to avoid rust. Annually
5	Target product cost	Pulley must be changed to new to maximize the performance. Estimate product cost: RM 500.00 to RM 1000.00
6	Availability of components	The standard components that can be bought at the hardware store.
7	Size and weight	Size: The size of the rack is expected to be the same as the rack of the kayak storage outside the campus Weight:
8	Manufacturing Facilities	Build a new rack with a unique design
9	Aesthetics and finish	Use a spray or paint that can attract customers and avoid corrosion.

10	Materials	Steel, hollow steel, roller, chain, pulley, and pedal
11	Product life span	Three years
12	Standards and specification	Follow the basic kayak size: 9 to 12 feet long (274 cm to 365.76 cm)
13	Ergonomics	Must follow RULA, REBA, and WERA
14	Quality and reliability	Time to failure: Due to how users use the rack. Maintenance: Low because to do monthly and annually Manufacturing process: Welding
15	Processes	Cutting Measuring Analyzing Testing Simulation
16	Testing	Structure Durability Functional Safety
17	Safety	Use a clamp to prevent the kayak from falling to the customer Follow the full ergonomics principle

3.2 Functional Structure

Functional decomposition uses a structured breakdown into a hierarchy of sub-functions to give a full description of how a complex system works [9]. Figure 3 shows the functional decomposition of an improved kayak rack system. The storing kayak includes a body, rack holder, and lifting mechanism. Later, these functional structures were used to create the function structure.

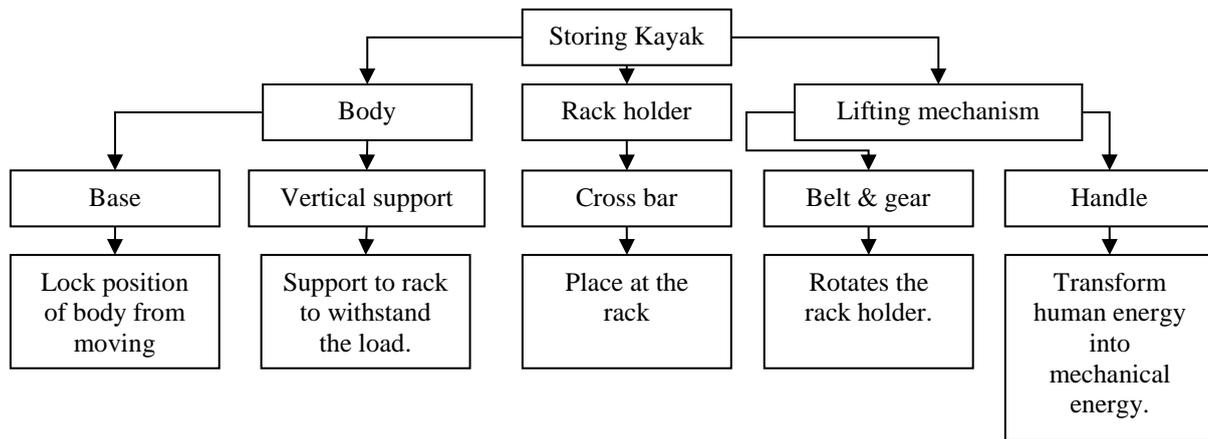


Figure 3: Functional Decomposition of an Improved Kayak Rack Systems

3.3 Functional Structure

The function structure shown in Figure 4 is a graphical illustration of a functional model. Function structure models provide a way for designers to analyze a system based on its functions and the interconnections among these functions, while also distinguishing the functions from their respective carriers [10]. The two types of flow, material flow, and energy flow, are easily understood. The flow of materials involves transferring the kayak from the ground to its racks using mechanical energy. This energy is used to lift the kayak onto the rack and rotate the handle. The lifting mechanism in the concept allows the rack holding the kayak to move up or down. This proposed functional structure, when compared to the existing product, will provide at least 50% of human energy use when lifting the kayak to the shelves, especially to the top shelves.

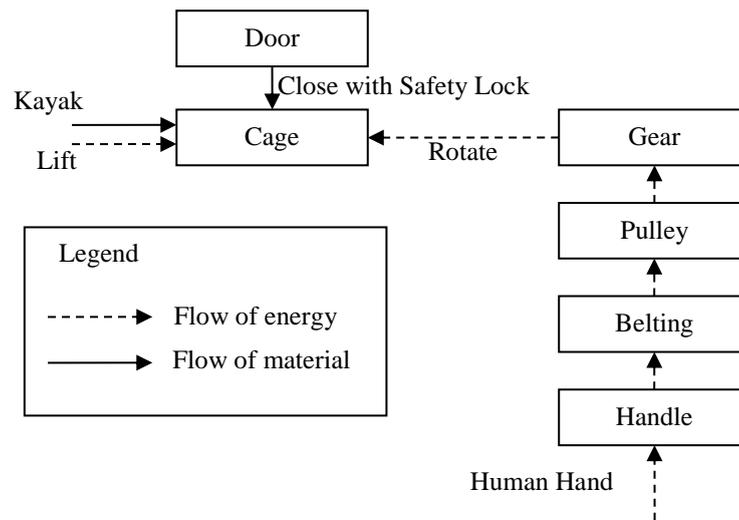
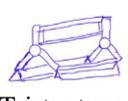
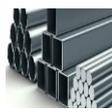


Figure 4: Function Structure of an Improved Kayak Rack Systems

3.4 Concept Generation

The morphological method is structured to allow for the intentional and systematic generation of a vast number of analogous solutions within defined sets of engineering design parameters [11]. Table 7 shows the morphological chart for the improved kayak rack. The chart is characterized by its identified list of device sub-functions, which is located on the left side of the chart. The possible option solution for each sub-function is placed on the right side of the chart. There are four sub-functions, and each sub-function has at least three option solutions. Later, five concepts are made through the possible combinations of option solutions for each sub-function, as shown in Table 8.

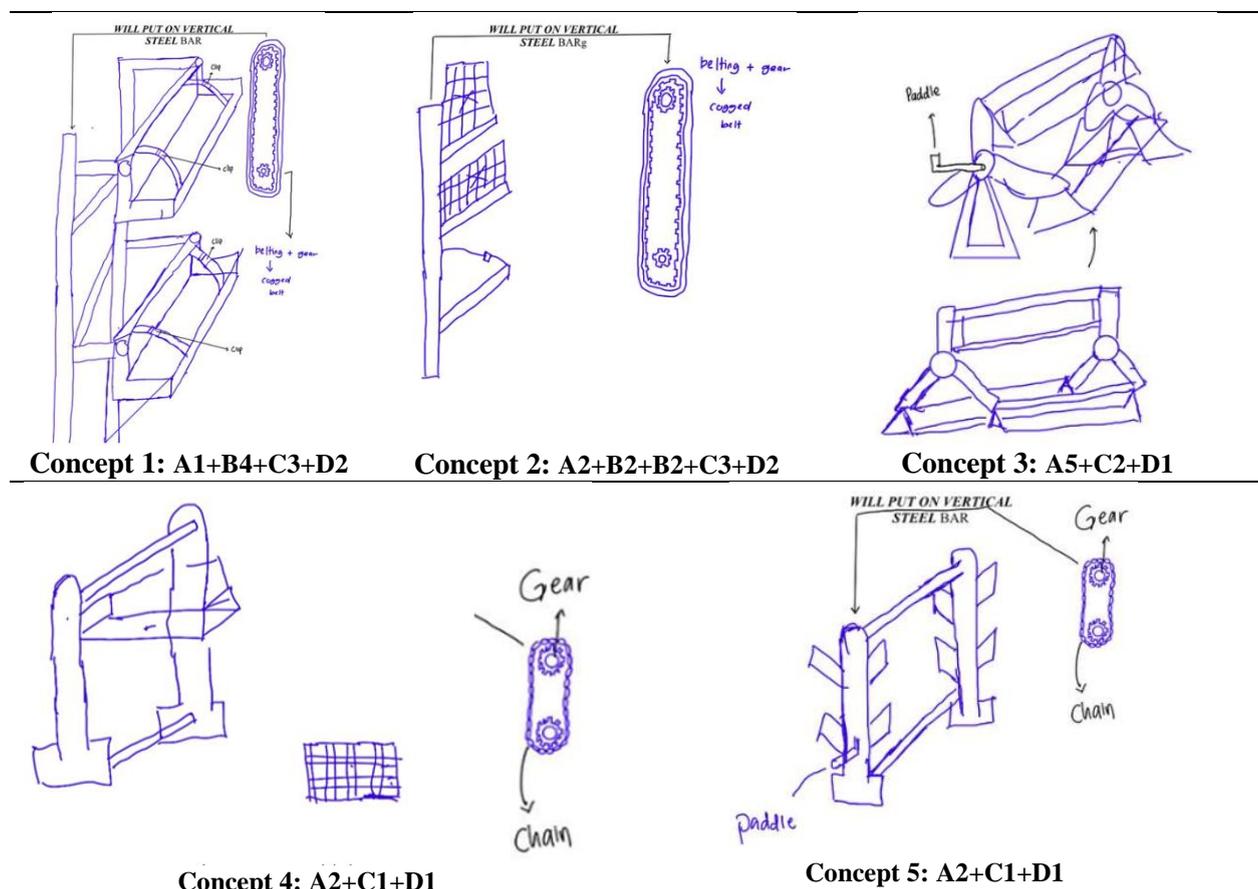
Table 7: Morphological Table for an Improved Kayak Rack System

Sub-function	Option-solution 1	Option-solution 2	Option-solution 3	Option-solution 4	Option-solution 5
Holder	A1  H-type	A2  Y-type	A3  F-type	A4  I-type	A4  Tristar type
Lock	B1  Rope	B2  Cage	B3  Slider	B4  Clip	None
Mover & lifter	C1  Gear and chain	C2  Paddle	C3  Belt and gear	None	None
Material	D1  Steel	D2  Stainless steel	D3  Alloy	D4  Wood	None

The possible combinations of option solutions for each sub-function are described below;

- i. Concept 1, for instance, utilizes an H-holder for storing the kayak, as illustrated in Table 8. This concept introduces a clip to facilitate the securing procedure, simplifying user interaction with the system. Moreover, using belt and gear machine tools in this concept helps lower maintenance costs.
- ii. Concept 2, on the other hand, incorporates a Y-type holder. This design choice simplifies removing the kayak from the rack, enhancing the user experience. The use of cages and clips provides additional security measures. This concept's design of belts and equipment is also noteworthy, as it requires minimal upkeep, thus reducing long-term maintenance efforts.
- iii. Concept 3 uses the control mechanism for the shelves, achieved through a paddle and a tri-star-shaped holder. This design provides a distinctive user interaction with the system.
- iv. Concept 4 takes a different approach by utilizing I-shaped holders. The simplicity of these holders contributes to the overall aesthetic of the system. The kayak is further reinforced with a protective enclosure, adding an extra layer of security. The use of gear and chains in this concept not only facilitates the identification of spare components but also ensures the standard functionality of the system.
- v. Concept 5 uses a Y-shaped holder in the final concept to enhance safety measures. It integrates an angled design to minimize the drying process, demonstrating a thoughtful consideration of the practical aspects of kayak storage. The chain and gear in this concept provide standard functionality, ensuring the system's reliability.

Table 8: Sketches for each Concept for an Improved Kayak Rack System



3.5 Concept Selection

The weighted decision matrix provides a clear and structured framework for evaluating options based on their alignment with specific criteria [12]. The five concepts from Table 8 are evaluated using the Weighted Decision Matrix to determine the final concept. These concepts are compared to the datum, the existing kayak rack available on the campus. The weighted decision matrix results are shown in Table 9.

The net scores for Concepts 1 until 5, as presented in Table 9, are 12, 20, 11, 16, and -6 respectively. These scores are crucial for providing a quantitative measure of the capability of each concept. Concepts with higher scores demonstrate higher potential.

Concept 2, with the highest score of 20, stands out among the rest and is therefore selected as the final concept. This decision is based on its superior performance in several key areas, which are worth discussing in detail:

- i. **Lifting Mechanism:** The lifting mechanism enables easy and efficient kayak handling. This feature reduces the effort required by the user.
- ii. **Accessibility:** Easy use of the kayak rack is ensured for users of all abilities.
- iii. **Durability:** The product's longevity is built to withstand various environmental conditions. Over time, functionality and reliability are maintained.
- iv. **Cost-effectiveness:** Cost-effectiveness makes it an attractive option for budget-conscious users.
- v. **Safety Features:** The user and the kayak are protected by several safety features in the kayak rack.
- vi. **Ergonomic Design:** The ergonomic design enhances user comfort, reducing the risk of strain or injury.

Compared to the current kayak rack available on campus, Concept 2 demonstrates superiority in all these areas, making it a superior choice.

Table 9: Weighted Decision Matrix of Kayak Rack Systems

Parameter	Weightage	Datum	Concept				
			1	2	3	4	5
Load Capacitor	4	0	+	-	-	+	-
Size & Dimension	2	0	+	-	-	-	-
Lifting mechanism	3	0	+	+	+	+	+
Accessibility	4	0	-	+	+	+	+
Durability	4	0	+	+	+	+	-
Cost	3	0	+	+	+	+	+
Safety	3	0	+	+	+	+	-
Ergonomic	5	0	+	+	+	+	+
Maintainability	3	0	-	-	+	-	-
Storing duration	5	0	-	-	-	-	-
	+		24	28	22	26	15
	-		12	8	11	10	21
Net Score			12	20	11	16	-6

4.0 CONCLUSION

In conclusion, this study has highlighted the need for an enhanced kayak rack at UiTM Cawangan Terengganu Kampus Bukit Besi through interviews and surveys. The customer requirements, identified from the data collected, were included in determining the engineering characteristics that were subsequently used in creating the House of Quality (HOQ) diagram.

The HOQ facilitated the identification of the most key customer and technical requirements, which were critical in the concept generation and selection activities. Consequently, a product design specification (PDS) for the kayak rack was developed based on the HOQ, serving as a concept generation and selection guideline.

The morphological method and weighted decision matrix were utilized to generate and select the final concepts. Concept 2 appeared as the optimum concept for the kayak rack system, excelling in ergonomics, cost, accessibility, durability, and lifting mechanism. This concept will enhance kayak storage operations at the UiTM Cawangan Terengganu Kampus Bukit Besi. It will proceed to the subsequent phases of the mechanical engineering design process, including embodiment design, detail design, and prototype.

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