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Helmet Stick Design for BC3 Paramlympic Bocia Games

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ABSTRACT

Boccia is one of the fastest-growing Paralympic sports and one of the few sports to have an Olympic rival. The BC3 boccia class is intended for athletes with locomotor dysfunction so severe in all four extremities that they require assistance from assistants and aids in the form of ramps and helmets equipped with pointer sticks. Therefore, the design of the BC3 boccia stick helmet was carried out to meet the needs of the athletes. The design was carried out by action research methodology with the concept of design, static simulation, manufacturing, and the house of quality. The design is divided into three main parts: the helmet bracket, shaft, and lock with bearings using M4 and M8 bolts. Static and design simulations used Fusion 360 and Ansys 2021 R2 software to determine design strength value. Stainless steel material is used in the design, considering the material selection using the Ashby diagram method. The maximum displacement value produced by design is 0.006 mm, and the minimum safety factor is 9.15. The manufacturing results produced helmet products with adequate accuracy and safety standards. A house of quality (HOQ) of 39% indicates that it can meet consumer needs better than other products.

1. INTRODUCTION

Paralympic sports are competitions for people with physical, mental, and sensorial disabilities. Initially, disability sports were only intended for rehabilitation and recreation. However, over time, sports by people with disabilities have become aimed at achievement, not only rehabilitation and recreation. There have been many competitive Paralympic sports that can be classified according to disability categories. Over the past few years, the Paralympics have gained a high public profile and have received more attention from various parties, who will continue to develop the Paralympic games [1].

Boccia is one of the fastest-growing Paralympic sports and one of the few sports to have an Olympic rival. This sport, regulated by the Boccia International Sports Federation, is a precision sport designed for individuals with cerebral palsy that affects motor skills. According to the World Health Organization (WHO), cerebral palsy (CP) is a chronic, non-progressive brain injury that can occur during the prenatal, perinatal, or first to the fifth year of life and is characterized by motor impairment. Boccia sports are distinguished by the purpose of competition, which depends on the players' physical and functional abilities [2]. Boccia athletes are classified in one of four classes: BC1, BC2, BC3, or BC4. The BC3 athlete class is intended for athletes with very severe locomotor dysfunction in all four extremities; they have no sustained gripping or release motion, and have short range of motion to get the boccia ball onto the court [3]. Therefore, they need some help from assistants and tools in the form of ramps and helmets equipped with pointer sticks, as shown in Figure 1.

The boccia National Paralympic Committee (NPC) in Surakarta has some of the leading boccia athletes who have had various achievements at both national and international levels. Boccia with a BC3 classification is now starting to be developed at the Surakarta NPC in order to represent Indonesia at the ASEAN Para Games (APG) in Vietnam in 2021 and strengthen the Central Java NPC boccia team in order to compete in the 2021 Papua National Paralympic Week (Peparnas). Moreover, it supports boccia to be more successful at national and international levels. Facilities in the form of tools play an important role when used in BC3 class boccia games [3, 4]. In order to support the equipment requirements in the BC3 classification of boccia, NPC Surakarta needs to develop the pointer stick helmet. The boccia helmets available in the market still have a low level of accuracy with athlete safety and comfort standards that have not been met, which can affect the safety and the result of the boccia games. This is because the helmet's function is crucial in the BC3 classification of boccia sports; namely, it helps the athlete direct the ball, roll the ball, and aim at the ball's target direction [5, 6].

A helmet stick is designed to produce a stick helmet product with adequate accuracy and safety standards based on the above explanation. Helmets are specially designed and developed based on the criteria desired by NPC Surakarta.

Figure 1. Boccia Sport Class BC3

2. METHOD

The research method used in this study is the action research (AR) method. Action research aims to improve the application of the methods/approaches of practitioners in the appropriate field of science. In addition, this research uses engineering methods, namely carrying out design activities [7]. The design uses numerical methods and application simulation using the Fusion 360 and Ansys 2021 R2 applications.

Based on the concept of design and identification of consumer needs that have been made obtained, benefits such as the value of HOQ products can be achieved correctly, simplification of sketches to create effective and efficient products, and the selection of materials that are more follow the design concept [8]. In general, the research steps are shown in Figure 2.

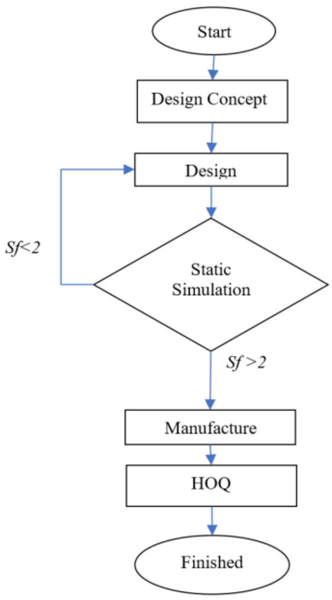


Figure 2. Research flowchart

2.1 Design concept

The design was made to identify the consumer demand for BC3 boccia sports equipment. The design was developed from an existing design to achieve effective and efficient use. The design idea of this article was developed from affirmative action research by interviewing members of the Surakarta NPC and BC3 boccia Paralympic athletes. Interview results also consider the house of quality (HOQ) assessment. The design is focused on the BC3 boccia helmet stick, which has a vital role in the boccia sport. Thus, the design is concerned with producing a stick helmet product with adequate accuracy and safety standards [2].

2.2 Design

The design is based on the design ideas and identified consumer needs to achieve the correct HOQ value for the product. The initial design was produced by creating an initial sketch using the Fusion 360 application. The sketch was divided into several parts to create an effective and efficient product [9]. On the other hand, the selection of materials to support the sketch was carried out according to the Ashby diagram method, taking into account the existing design concepts.

2.3 Static simulation

Static analysis for the framework of the boccia helmet stick sporting apparatus was carried out by simulating the load on the frame using Fusion 360 software. To increase the validity of the design, static simulations were also carried out using Ansys 2021 R2 software. This was aimed at determining the reliability of the strength and safety factors of the tool [10]. In the static simulation found in Ansys, the numerical method used is the finite element method to determine the deformation that occurs in the design.

In addition, to determine the reliability of the bearings, a bearing safety analysis was carried out using a numerical method. The bearing safety of the bolt connector was based on the tensile stress of the bolt [11]. Furthermore, the safety factor was calculated by [12].

$$S_f = \frac{yield\ stress}{calculated\ stress} \quad (1)$$

2.4 Manufacture

Manufacturing planning was conducted to find out how the design development was going. In addition, planning helps decide whether to manufacture or purchase individual parts. This made it easy to analyze the needs of the machines used in production to process each part. Manufacturing was carried out based on the planning conducted [13, 14].

2.5 House of quality (HOQ)

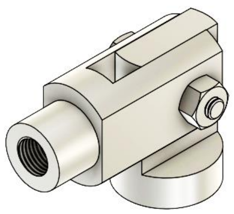
The House of Quality (HoQ) is a popular design tool that supports information processing and decision-making in the engineering design process. While its application is an aid to conceptual aspects of the design process, its use as a quantitative information tool in engineering design is potentially flawed. This Flaw results from potential designer interpretations of HoQ results — invalid interpretations given the assumptions and sources of information behind HoQ — and are seen as critical limitations on method outcomes that can lead to potentially invalid and bad decisions [15].

House of quality (HOQ) delivers high-quality performance to determine the value of a product that consumers expect. HOQ can be used to define design modules, subsystem characteristics, and manufacturing processes for early identification to ensure product quality. This method also allows the properties of the main components to be compared with the primary manufacturing process [9, 11, 16].

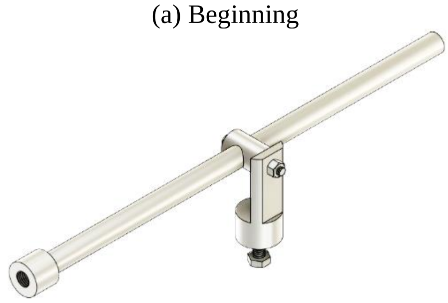
3. RESULTS AND DISCUSSION

3.1 Design concept

The use of sticks on the BC3 boccia helmet is necessary for boccia Paralympic athletes. Helmet sticks propel the ball; thus, a strong and flexible design is required. Helmet stick strength is based on the safety value of the BC3 boccia helmet stick design. The research was conducted by designing a BC3 boccia helmet with a simple design, accessible materials, and ease of operation. The boccia stick helmet uses a ball guide, ball scroller, and ball direction target, which can also be developed to increase accuracy in the game. The initial sketch design concept is as shown in Figure 3(a). Because the ball propulsion shaft is not long enough, which makes it difficult for the boccia athlete to push the boccia ball [2], the improvement of the sketch was carried out as shown in Figure 3(b).



(a) Beginning



(b) Final

Figure 3. Sketch

3.2 Design

After achieving a basic design, a drawing of the tool was carried out using the Fusion 360 software. The drawing was made into three parts: a helmet bracket part, shaft part, and locking part, as shown in Figure 4. This three-part division was to make it easier to assemble the tool. The total design volume is 105350 mm^3 with a weight of 0.82 kg.

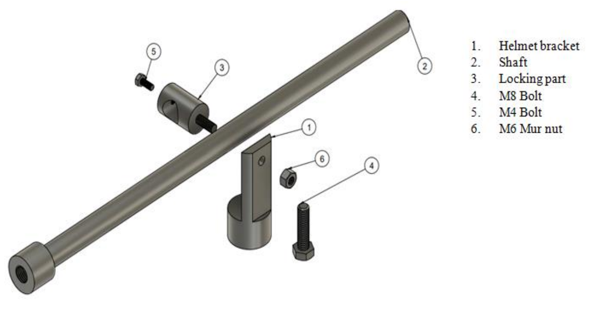
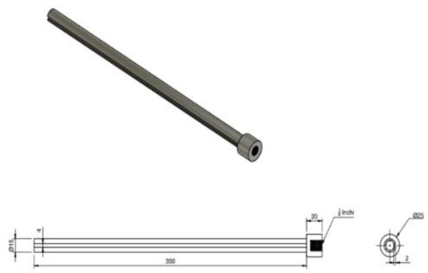
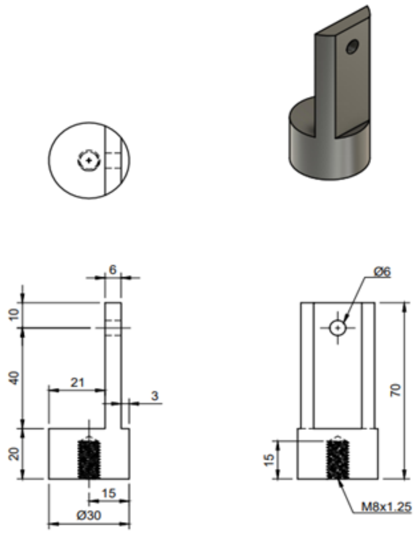


Figure 4. BC3 boccia helmet stick assembly

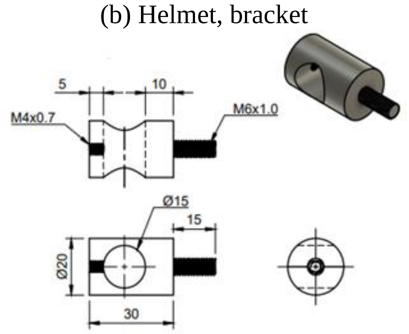
The design in Figure 4 shows that the shaft part is indicated by number 2, the locking pin at number 3, and the helmet bracket at number 1. While in other parts, it serves as bearings. The tool size for each part was adjusted to the height and average load. This is so that the tool can have good safety standards. The sizes for each part are shown in Figure 5, in millimeters.



(a) shaft



(b) Helmet, bracket



(c) Locking pin

Figure 5. Parts

The bearings are located at the junction of the helmet bracket, shaft, and locking pins. The bearings are two pieces between the shaft and the helmet bracket. Bearings use bolts and nuts with bolt sizes M4 and M8 and a nut size of 6. Details of the bearing drawings can be seen in Figure 6.

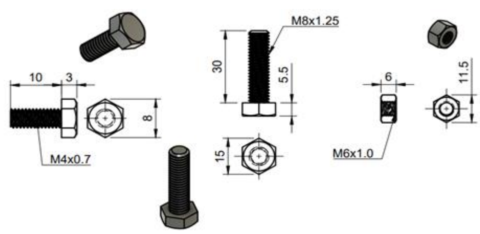
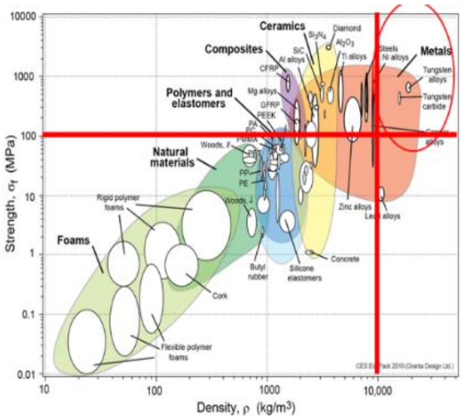


Figure 6. Bearing (Nut and Bolt)

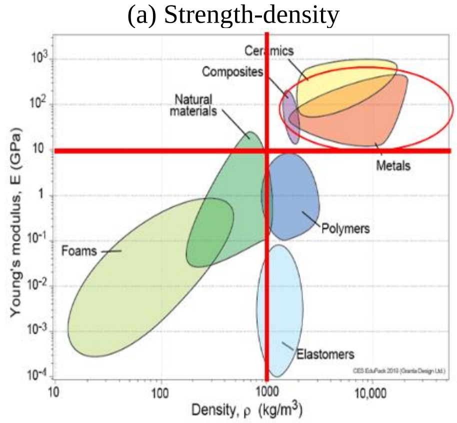
Under the basic drawings and designs, the Ashby diagram was used to select the base material for the BC3 boccia helmet stick. We selected the value based on the vertical curve to compare with the horizontal curve based on the specified value; in this case, this is on the red axis boundary. The material requirements were determined according to the classification of strength, density, and Young's modulus, as shown in Figure 7. Materials that met the standards were obtained by selecting metal-based materials; therefore, stainless steel was used in this design [17]. The specifications of the materials used can be seen in Table 1.

Table 1. Specifications of stainless steel material

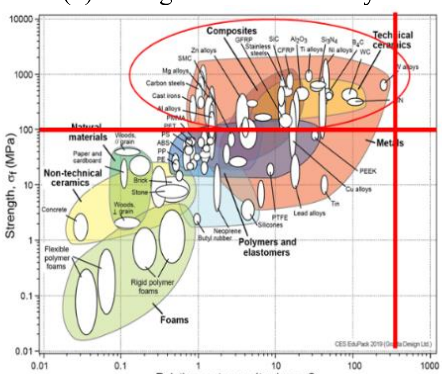
Density	8E-06 kg/mm^3
Young's Modulus	193000 MPa
Poisson's Ratio	0.3
Yield Strength	250 MPa
Ultimate Tensile Strength	540 MPa
Thermal Conductivity	0.0162 W/(mm C)
Thermal Expansion Coefficient	1.04E-05/℃
Specific Heat	477 J/(kg ℃)



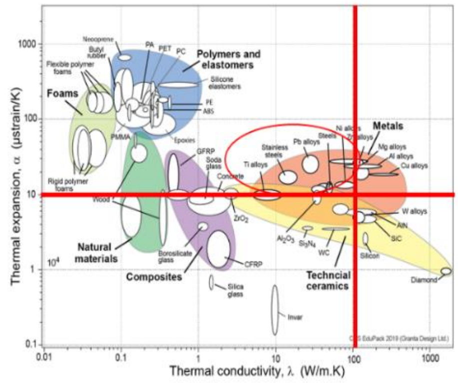
(a) Strength-density



(b) Young's modulus-density



(c) Strength-cost



(d) Thermal expansion-conductivity

Figure 7. Material selection

3.3 Static simulation

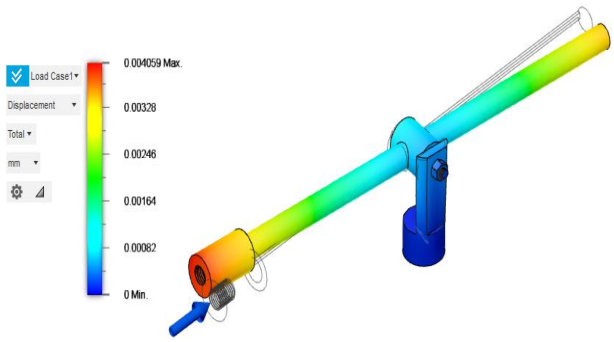
Static analysis on the boccia helmet stick was carried out using the Autodesk Fusion 360 and Ansys 2021 R2 software applications. The loading was carried out evenly on the surface directly exposed to the ball load. In this analysis, the pedestal was fixed rigidly on the surface of the stick–helmet connection. The load is given based on the weight of the ball, with a safety value of 2, which is 5.56 N. It is known that the accuracy of a simulation depends on the quality of the mesh [18]. Meshing was carried out with the specifications shown in Table 2. The meshing results have a good standard with a skewness of 0.54023 [19]. As shown in Figure 8, the contours of the simulation design changes are similar to each software used. Contours evenly distributed on the safety factor indicate that they have the same strength value. Although the displacement with the red contour indicates the most likely damage, it can be seen that, in the simulation using Fusion 360 software, the design has a maximum displacement value and a minimum safety factor of 0.004 mm and 9.15, respectively. While using the Ansys 2021 R2 software, the maximum displacement and minimum safety factor values are 0.006 mm and 15, respectively. The complete simulation results can be seen in Table 3. This indicates that the materials and material and framework structures used in the design have good safety standards [20].

Table 2. Specification of meshing

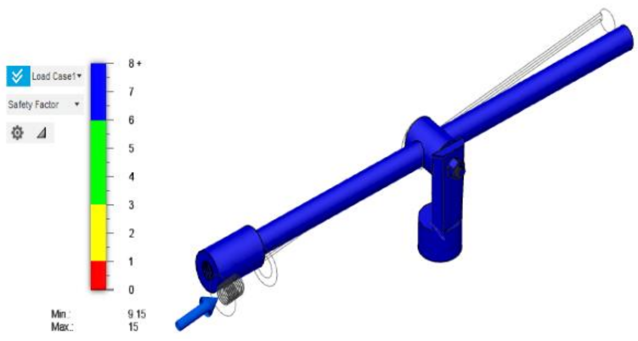
Software	Nodes	Elements
Fusion	119225	73528
Ansys	110700	63938

As for bearing reliability, numerical analysis results show that bolt bearings are estimated to have a good safety factor from the design results. This is because the tensile stress of the bolt bearings used has a value smaller than the allowable tensile stress of the bolt bearings, as calculated in Table 4. Thus, this tool can operate with reliable power and last longer [21-23].

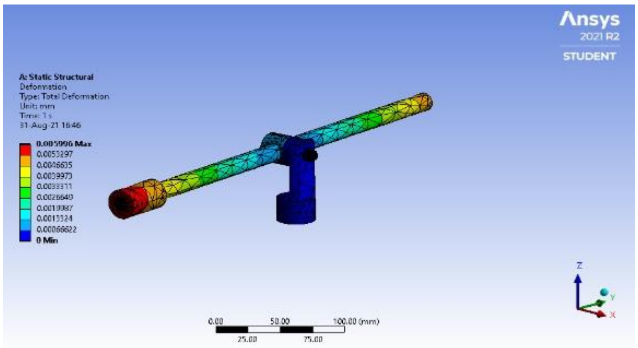
After the design analysis produced the required data, the next step was to plan the purchase of the necessary manufacturing goods. This was to ensure that the design could be carried out within the existing price constraints. For its manufacture, materials are needed with a total price of Rp 351.500, as shown in Table 5. In this case, the design is still within the range of production costs. In addition, this design is cheaper than other BC3 boccia helmets because it has a high strength value.



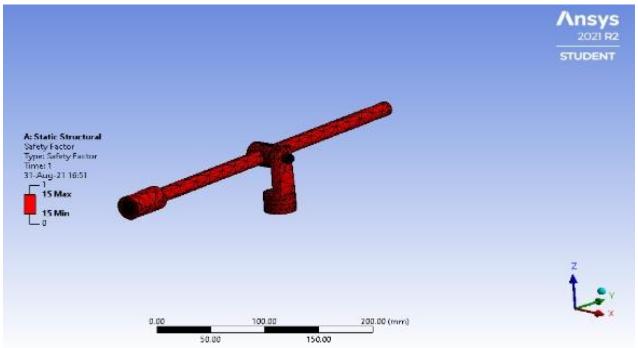
(a) Displacement, Fusion 360



(b) Safety factor, Fusion 360



(c) Displacement, Ansys 2021 R2



(d) Safety factor, Ansys 2021 R2

Figure 8. Simulation results

Table 3. Design strength simulation results

Software	Displacement (mm)		Strain (mm/mm)		Stress (MPa)		Safety Factor	
	Min	Max	Min	Max	Min	Max	Min	Max
Fusion 360	0	0.004059	9.88E-14	2.41E-04	1.18E-08	27.32	9.15	15
Ansys 2021 R2	0	0.006	-7.92E-06	8.28E-06	-0.58376	0.61005	15	15

Table 4. Numerical analysis of bearings

M4x0.7. Bolt				M8x1.25. Bolt			
Type	Formula	Results	Information	Type	Formula	Results	Information
d	Bolt property	4	Nominal diameter of the thread (mm)	d	Bolt property	8	Nominal diameter of the thread (mm)
de	Bolt property	3.515	Effective diameter(mm)	de	Bolt property	7.188	Effective diameter(mm)
in	Bolt property	3,242	Thread core diameter(mm)	in	Bolt property	6,647	Thread core diameter(mm)
W	Ball properties	0.556	Load (kg)	W	Ball properties	0.556	Load (kg)
τa	Bolt property	6	Allowable Tensile Stress (kg/mm^2)	ta	Bolt property	6	Allowable Tensile Stress (kg/mm^2)
v	property	2	Safety factor	v	property	2	Safety factor
τa	τa.v	3	Final allowable tensile stress (kg/mm^2)	ta'	a.v	3	Final allowable tensile stress (kg/mm^2)
τt	$\frac{4.W}{\pi.di}$	0.067387464	Tensile Stress (kg/mm^2)	yyyy	$\frac{4.W}{\pi.di}$	0.016031	Tensile Stress (kg/mm^2)

Table 5. Bill of materials

No	Name	Specification	Quantity	Unit price (Rp. ,-)	Total price (Rp. ,-)
1	Stainless Steel	Diameter 32 mm, length 50 cm	1	45000	45000
2	Stainless Steel	Diameter 20 mm, length 20 cm	1	35000	35000
3	CNC Hose	30 cm long, made of plastic	1	65000	65000
4	myrrh	M6	1	1000000	1000000
5	Bolt	M4	1	2000	2000
6	Bolt	M8	1	2000	2000
7	Ring		6	250	1500
9	Lathe Cost		1	200000	200000
		Total			351500

3.4 Manufacture

In making a boccia helmet, the design is divided into two steps: determining the use of the machine and determining the quality of each part [24]. It can be seen that the manufacturing plan is divided into six parts, of which three parts are produced independently, and three parts are purchased, as shown in Table 6. It has an effective and efficient value for the planned parts. Manufacturing classifications are shown in Table 7.

Manufacturing was successfully carried out, as shown in the figure. Splicing for each part was performed to find out manufacturing errors in each part. Inspections were carried out by visualization and testing by athletes, as shown in Figure 9. The boccia helmet has a good safety and comfort value and can be used as a supporting tool for BC3 boccia sports competitions [2].

3.5 House of Quality

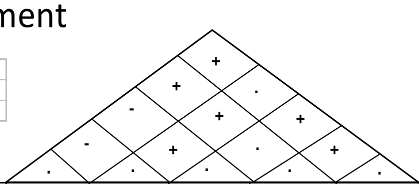
The quality of the tool design was assessed using the house of quality system. The evaluation that was conducted found that the designed product can meet the consumer needs better than other products. The design results show that it is most valuable due to a sturdy frame, the fact that it can be used by many people, and because it does not consume a lot of power during operation. Compared to the competition or other products [7], the design has a better score (39%), as shown in Figure 10.

(a) Results (b) BC3 boccia helmet trial

Figure 9. BC3 boccia helmet

Quality Function Deployment

Project Title: Boccia BC3 Helmet
Project Leader: Zainal Arifin
Date: 31-Aug-21



Correlation:	+	.	-
	Positive	No correlation	Negative

Relationships:	9	3	1	
	Strong	Moderate	Weak	None

		Desired direction of improvement (↑,0,↓)	↑	0	↑	↑	0				
	1: low, 5: high	Functional Requirements (How) →	Material	Fuel	Working Mechanism	Strength	Storage Power	Weighted Score	Competitive evaluation (1: low, 5: high)		
No	Customer importance rating	Customer Requirements - (What) ↓							Design	Kompotitor 1	Kompotitor 2
1	5	The tool is easy to operate			9	9		90	5	4	3
2	3	Can be used by many people	3		9	9		63	4	3	4
3	4	The tool is not easily damaged / broken	9			3		48	5	4	3
4	2	Tool does not rust easily	9			3		24	3	4	3
5	3	Flexible or knockdown	3		9			36	4	5	3
6	1	Does not drain a lot of energy / effective			9	3		12	4	5	3
7	4	Economical tool prices	3					12	5	2	3
8	4	The price of running equipment is cheap			9	9		72	4	2	3
9	4	Tools are easy to interpret	3		3			24	3	4	4
		Technical importance score	96	0	156	129	0	381	4.267717	3.519685039	3.2283465
		Importance %	25%	0%	41%	34%	0%	100%	39%	32%	29%
		Priorities rank	**3**	**4**	**1**	**2**	**4**				
		Current performance	3		4	3					
		Target	3		4	3					
		Benchmark	4		3	2					
		Difficulty	2		3	2		1: very easy, 5: very difficult			
		Cost and time	3		2	3		1: low, 5: high			
		Priority to improve	**3**		**5**	**4**					

Figure 10. House of quality products

Table 6. Machining process classification

Part Number	Part Name	Tapping	Counterboring	Drilling	Milling	Grinding	Shaping	Fillet	chamfer	Other
1	Base/main stand	M8	N	N	Y	N	N	N	N	
2	Axis	M12	N	N	Y	N	N	N	N	
3	Lock pin	M4	N	N	Y	N	N	N	N	
4	M8. bolt									Purchased
5	M4. bolt									Purchased
6	M6 nut									Purchased

Table 7. Manufacturing Classification

Part		**DFA Complexity**		**Functional Analysis**		**Error Proofing**	**Handling**			**Insertion**					**Joint**			
Part Number	Assembly Image 	Number of Parts (Np)	Number of Interfaces (NI)	Part Can Be Standardized	Cost (Low/Medium/High)	Assemble Part Wrong Way around	Tangle/Nest/Stick Together	Flexible/Fragile/Sharp/Slippery	Pliers/Tweezers/Magnifying G	Difficult to Align/Locate	Holding down Required	Resistance to Insertion	Obstructed Access/visibility	Re-oriented Work Piece	Screw/Drill/Twist/Rivet/Bend/Cr	Weld/Soldering/Glue	Paint/Lube/Heat/Apply Liquid or G	Test/Measure/Adjust
1	Base/main stand	1	1	N	M	Y	N	N	N	Y	Y	N	N	Y	Y	N	N	Y
2	Axis	1	1	N	H	Y	Y	N	N	Y	Y	N	N	Y	Y	N	N	Y
3	Lock pin	1	1	N	M	Y	N	N	N	Y	Y	N	N	Y	Y	N	N	Y
4	M8. bolt	1	1	Y	L	N	N	N	N	N	N	N	N	N	Y	N	N	N
5	M4. bolt	1	1	Y	L	N	N	N	N	N	N	N	N	N	Y	N	N	Y
6	M6 nut	1	1	Y	L	N	N	N	N	N	N	N	N	N	Y	N	N	N

4. CONCLUSIONS

The design of the BC3 boccia helmet was successfully carried out. The BC3 boccia helmet is intended for BC3 boccia athletes at NPC Surakarta. The BC3 boccia helmet stick became the focus of the design process. A stick with a volume of 105350 mm3 and a weight of 0.82 kg was designed. The design was divided into three main parts: the helmet bracket, shaft, and lock. The bearings used M4 and M8 bolts. The design process was equipped with a simulation of design strength. With meshing with a skewness quality of 0.54023, the maximum displacement value is 0.006 mm, and the minimum safety factor is 9.15. The manufacturing results produced a stick helmet with adequate accuracy and safety standards. A house of quality design of 39% indicates that it meets consumer needs better than other products.

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