Preliminary Design for Assembling and Manufacturing Sports Equipment: A Study Case on Aerobic Walker

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***Abstract*—One way to increase the interest of the community in exercising is providing sport equipment which is integrated with the tourist site. One exercise tool that can be applied is aerobic walker type outdoor fitness equipment. Aerobic walker is a tool with the principle of static walking. This article discusses the planning of aerobic walker type outdoor fitness equipment products using the design for manufacturing and assembly (DFMA) method and calcifications using the house of quality (HOQ) methods in which the design is based on drawings, materials, analysis, and equipment production plans. The method used in this research is action research, numerical engineering and application of simulation using the Autodesk Fusion 360 application. The design of the tool can be used by two people with an average weight of 80 kg and operating with a maximum speed of 30 rpm. The design results are divided into 3 parts: the main frame, foot handle, and footrests made of carbon steel with 6010 bearing types. The safety value of the tool for safety factor and the tool bearing age factor are 15 and 12128.52 hours, respectively. Based on consumer needs with the house of quality method, the design of this tool has a value of 3.9 and is better than other fitness equipment (52 hours).**

***Index Terms*—preliminary design, assembly and manufacture reference, aerobic walker, DFMA, HOQ**

I. Introduction

One of the shortcomings of tourism area promoting health awareness is the lack of awareness of people surroundings about exercise. This indicated by the lack of availability of sport facilities in that area. The majority of people are less interested in sports that are carried out in special places as a means of recreation. One of the ways to overcome this problem is by providing sports facilities that are integrated with tourist parks in order to attract the interest of the community in exercising [1-4].

One of sport facilities that can be used by all groups is outdoor fitness equipment, because it can be applied as a recreation for people who visit the tourist parks. That suitable fitness equipment is called aerobic walkers which have principle of static walking. Therefore, this equipment can encourage people to do physical activities that are easy, simple, and inexpensive. If this can work effectively, this physical activity can increase surrounding community health and reduce the chance to get disease. However, the use of an aerobic walker type outdoor fitness equipment requires proper planning and design so that the equipment can be used for a long time and can be used by everyone. The design is possibly adopted based on engineering design as previously conducted by Caesar et al. [5] and Ary et al. [6] which considered material and structure geometry in designing hardness tester facility and analyzing structural design of eco-vehicle chassis.

Based on these problems, the authors are interested in planning an aerobic walker type outdoor fitness equipment product. Planning is conducted using the design for manufacture and assembly method. The plan is carried out based on drawings, materials, and components needed in the tool-making process. In addition, this investigation is complemented by a quality function deployment (QFD) process using the house of quality (HOQ) method [7-10].

II. Design Methodology

The research method used in this research is the Action Research (AR) method. Action research aims to improve the ways of practitioners in applying appropriate fields of science [8]. In addition, this study uses engineering methods based on the design activities. The design was made by using numerical methods and simulation using the Fusion 360 software. In general, the flowchart of this research is shown in Fig. 1.

Manuscript received July 8, 2020; revised January 3, 2021.
Grant name: PNBP UNS Pengabdian Kepada Masyarakat (PkM)
Grant no.: 453/UN27.21/PN/2020

doi: 10.18178/ijmerr.10.3.107-115

A. Design Concept

The design concept is carried out to identify consumer needs for aerobic walker type outdoor fitness equipment. This is intended as a basis for building a tool so that it can be used efficiently and effectively. The design concept in this paper is carried out by active action research with interviewing several communities. The results of the interview are also used to consider the assessment of the house of quality (HOQ) method.

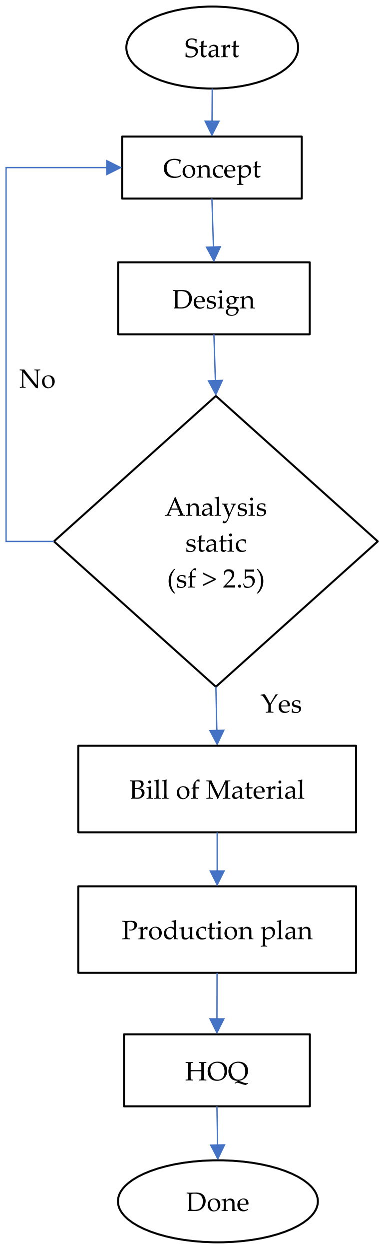


Figure 1. Flow chart of the current design research.

B. Design

Design is carried out based on the design concept and identification of consumer needs that have been made so that the product's HOQ value can be achieved properly. The sketch is divided into several parts in order to create an effective and efficient product. The most important part in designing an aerobic walker type outdoor fitness equipment is the bearing in which the choice of bearing is based on the equation listed in Table I. Ashby diagram is used for the selection of materials to get more appropriate design concepts.

TABLE I. FUNDAMENTAL PARAMETERS IN BEARING DESIGN [11]

Type	Formula	Information
Finding the Side Force (W)	$W = Wi\,.(F_1\,.F_2)$ (1)	Wi = 0.5 F_1 = Attraction style F_2 = Loose side tensile force
Finding the Gravity (Wp)	$Wp = (\pi.D^2.L).M$ (2)	D = shaft diameter L = shaft length M = density of shaft
Specific Equivalent Radial Load	$\Pr = X.V.Fr + Y.Fa$ (3)	V = factor which depends on rotating bearing and rotating inner ring X = Radial factor Y = angular axial factor 0o Fa = Axial load $Fr = W + Wp + Wi$
Planned Bearing Life	$H = j.T.h$ (4)	j = 8 hours H = 2 years h = 365 days
Selection of bearings (Dynamic load)	$C^3 = \left(\frac{H.60.n.Pr^3}{10^6}\right).Sf$ (5)	C = dynamic load (kg) n = 30 rpm Sf = 20

C. Design Analysis

The form of the existing design is carried out a static analysis for the aerobic walker type outdoor fitness equipment framework. Analysis was conducted by simulating the load on the framework using the Autodesk Fusion 360 software application. This aims to determine the reliability of the strength and safety factor of the tool. In order to determine the reliability of bearing life, nominal factor analysis and bearing reliability factor were carried out. The analysis was carried out using the numerical method as in Table II.

D. Bill of Material

Bill of material is an identification in classifying the needs for the type of shape and material of each design part for fabrication. This is the basis for providing a budget for building a design [12]. The prices listed in this paper correspond to market prices as of May 2020 in the city of Surakarta.

E. House of Quality (HOQ)

House of Quality (HOQ) is a method of Quality Function Deployment to identify the value of the product as desired by consumers. HOQ can be used for initial identification in understanding the shape of the design, characteristics of the sub system, the manufacturing process, and ensuring product quality [13]. In addition, this method can compare the characteristics of critical components and key operations in production.

TABLE II. PARAMETERS FOR NUMERICAL CALCULATION [11]

Type	Formula	Information
Speed Factor (Fn)	$Fn = (\frac{33,3}{n})^{\frac{1}{3}}$ (6)	n = 30 rpm
Bearing General Factor (Hfn)	$Hfn = Fn.\frac{C}{Pr}$ (7)	C = dynamic load bearing used Pr = design load / actual
Bearing Nominal Factor (LH)	$LH = 500.Hfn$ (8)	
Bearing Life Reliability Factor (Ln)	$Ln = a_1.a_2.a_3.LH$ (9)	a_1 = 96% reliability a_2 = material factor a_3 = work factor
Safety Bearing Life (Si)	$Si = \left(\frac{Ln}{H}\right)$ (10)	

III. RESULTS AND DISCUSSION

A. Physical Criteria on the Sport Equipment

Based on the requirements given, the aerobic walker type outdoor fitness equipment design concept has some criteria including the capacity of the tool that can be used by one person at a manufacturing cost of less than 10 million rupiah, the tool that has a strong structure with a safety factor of more than 2 against the average human load, which is about 80 kg and a height of 170 cm with a support of 2 bade bearings for each part, the tool that does not require other energy or fuel with a maximum tool rotating speed of 30 rpm, and the tool that is easy to repair and dismantle.

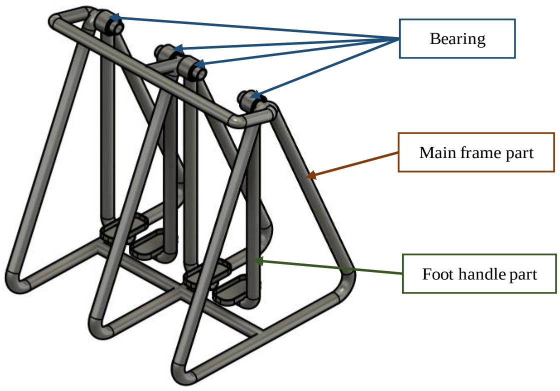


Figure 2. Three-dimensional geometry of the aerobic.

B. Engineering Drawing for Assembly and Manufacture

After having a basic design, a tool drawing was carried out using the Autodesk Fusion 360 software application. The image was made into 3 parts: main framework, footrests, and handle legs as shown in Fig. 2. The tool size for each part is adjusted to the height and the average load [14]. Thus, the equipment can have good safety standards as shown in Figs. 3 and 4 (the unit is in mm).

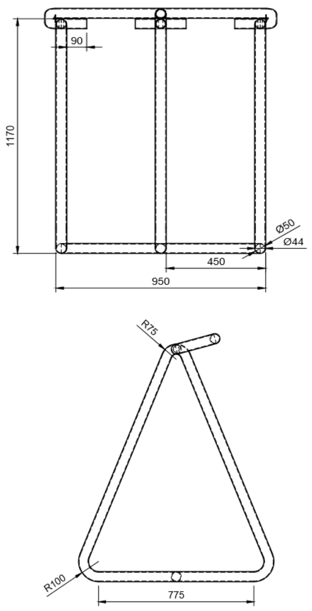


Figure 3. Dimensions specification of the main frame.

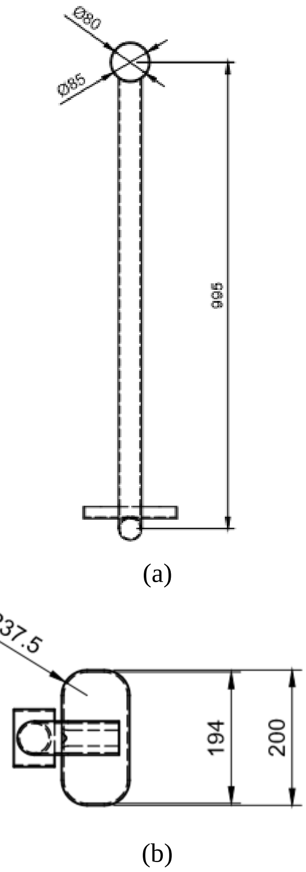


Figure 4. Dimensions specification of design part: (a) foot handle and (b) footrest.

Bearings were located at the joint of main framework and foot handle. Two parts of bearing were prepared in between the shafts for each sub part handle feet. Shaft diameter is designed at 50 mm with a length of 95 mm. Detailed image of the bearing can be seen in Fig. 5.

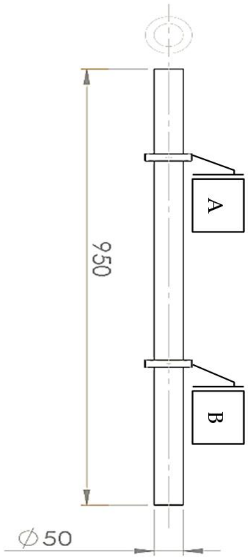


Figure 5. Dimensions specification of the bearing shaft.

The bearing shaft has two supports at point A and point B. Two bearings are the same because the diameter of the supports is the same. The force acting on the bearing is radial force; there is no axial force because no force is exerted on the horizontal axis towards the shaft. Therefore, the bearing type used is Single Row Angular Contact Bearing. The carbon steel shaft can spin up to a maximum of 30 rpm, while the tensile forces on the tight side and loose side are 100 kg and 80 kg. Details of bearing selection design can be seen in Table III.

TABLE III. RESULTS FOR THE BEARING DESIGN

Type	Result
Finding the Side Force (*W*)	10 kg
Finding the Gravity (*Wp*)	58.57 kg
Specific Equivalent Radial Load	38.67
Planned Bearing Life	5840 hours
Selection of bearings (Dynamic load)	1693.6 kg

From the design calculations and the diameter of the shaft size with the total dynamic load, a bearing 6010 is used with the following specifications which detailed image of the bearing is shown in Fig. 6.

- Diameter (*d*): 50 mm
- Diameter (*D*): 80 mm
- Wide bearing (*B*): 16 mm
- Radius (*r*): 1.5 mm
- Specific dynamic nominal capacity (*C*): 1710 kg
- Specific static nominal capacity (*Cp*): 1430 kg

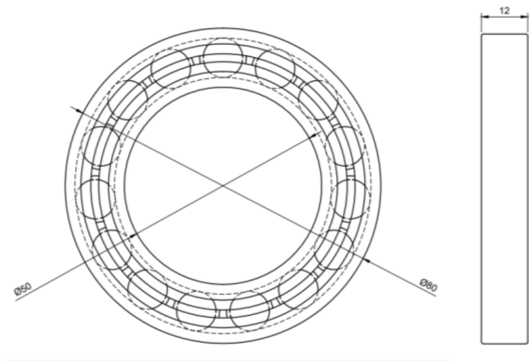
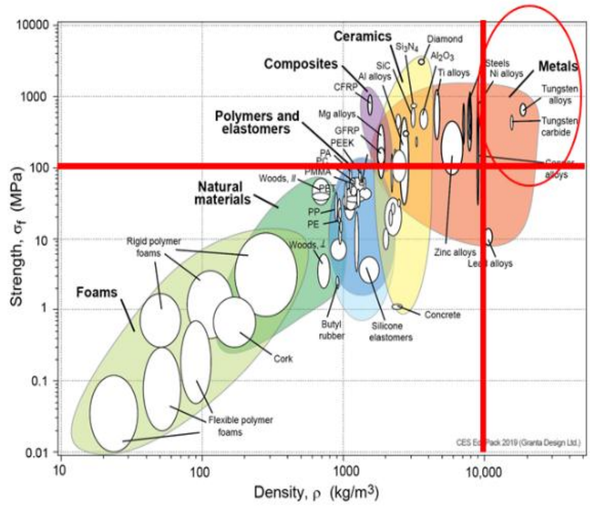
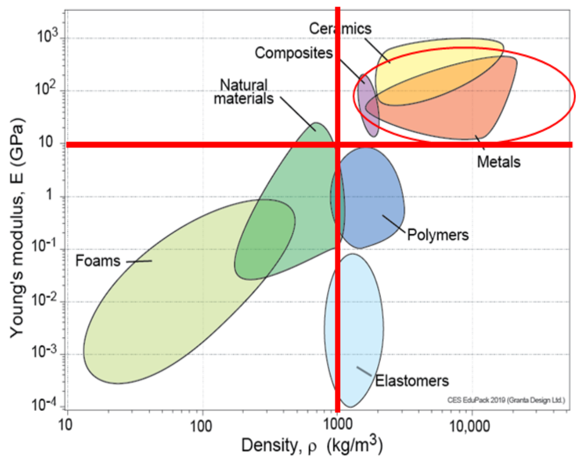


Figure 6. Dimensions specification of the bearing.

Based on the drawings and the design, the basic materials for the tools were selected using the Ashby diagram [15-17]. The selection is based on the number of strength and density which fulfil criteria as shown in the red circle line. In addition, identification of material requirements is also based on classification young modulus, thermal, and relative coast as shown in Fig. 7. From the selection, materials that match the criteria is in the family of metal so that carbon steel was used in this design.



(a)



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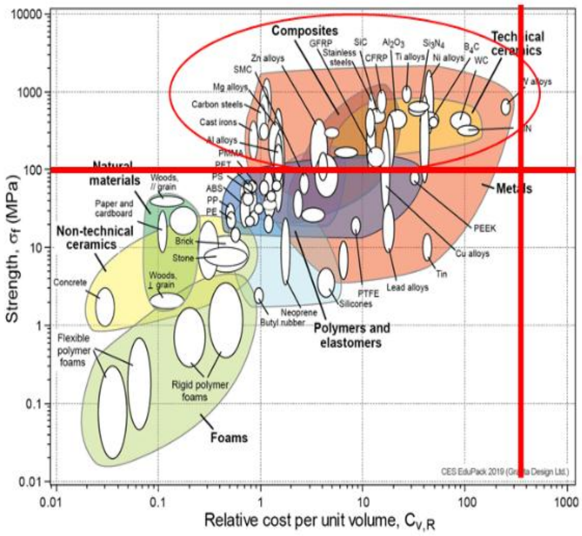

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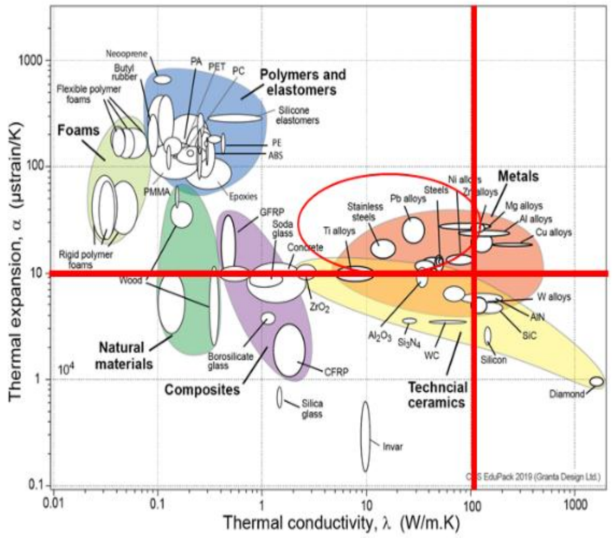
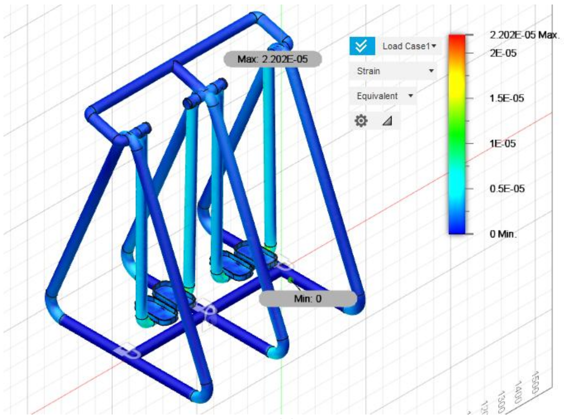


(d)

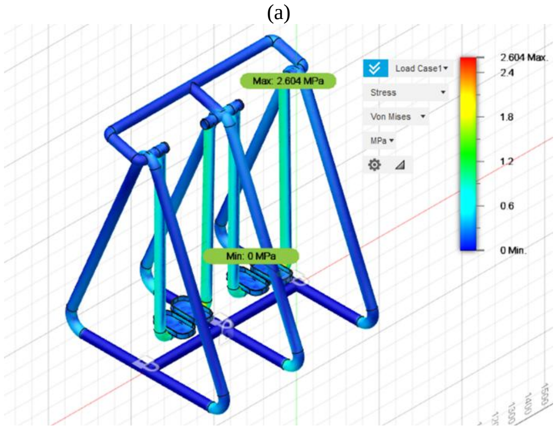
Figure 7. Material selection is based on (a) strength-density, (b) young modulus-density, (c) strength-coast, and (d) thermal characteristic.

C. Numerical Analysis on the Design

Static analysis on tools outdoor fitness type aerobic walker was performed using the Autodesk Fusion 360 deploying finite element codes in simulation [18-25]. The loading is carried out evenly on the footrests and bearing pipes. In this analysis the pedestal is rigidly at the bottom of the pipe. It can be seen that the design has a maximum value of strain, stress, displacement, and safety factor of 0.000022, 2.604 MPa, 0.1095, and 15 as shown in Fig. 8. This indicates that the materials and the structure of the framework used in the design have good safety standards.



(a)



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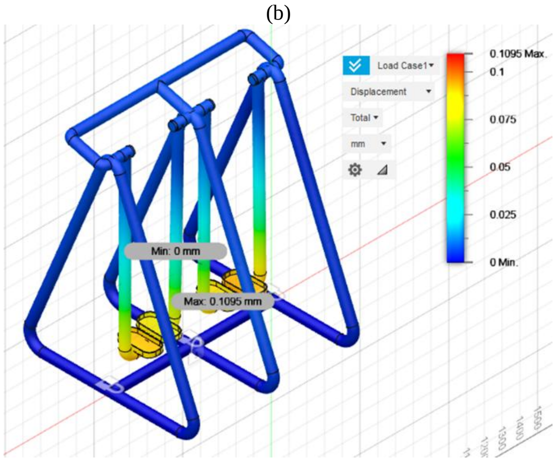

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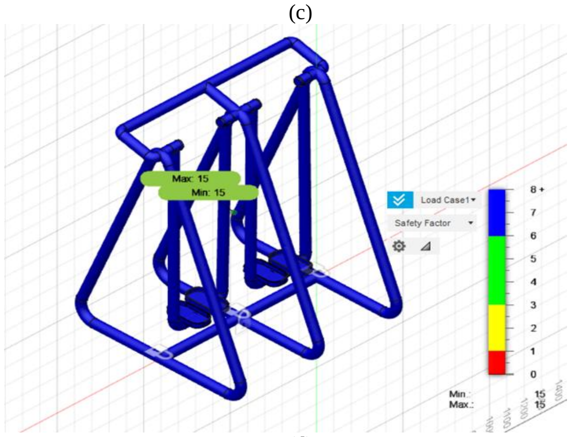


(d)

Figure 8. Simulation results of the structural design: (a) strain pattern, (b) structural stress, (c) component displacement and (d) safety factor.

For the reliability of the bearings, the analysis results show that the bearings are estimated to have a better bearing life factor than the design results. This is because the bearing life factor used has a value twice greater than the desired bearing life, as calculated in Table IV [9]. Therefore, tool can operate with a longer shelf life.

TABLE IV. RELIABILITY ANALYSIS ON THE BEARING DESIGN

Type	Result
Speed Factor (Fn)	1,035
Bearing General Factor (Hfn)	45.76
Bearing Nominal Factor (LH)	22884 hours
Bearing Life Reliability Factor (Ln)	12128.52 hours
Safety Bearing Life (Si)	2

D. Bill of Material

After the design analysis produces the desired data, it is then necessary to plan the purchase of the need to fabricate the equipment. This aims to determine the design can be made with existing coast boundaries. It can be seen that fabrication requires a material with a total price of Rp. 8,165,600 as shown in Table V. It means that the design is still within the cost range for fabrication. In addition, this design has a cheaper build value than other fitness equipment because the design does not require other fuels in operation.

TABLE V. BILL OF MATERIAL DESIGN

Name	Unit	Volume	Price (IDR)	Total (IDR)
Main Frame & Foot Handle				
Steel pipe Ø50 mm	Meter	5	200000	1000000
Steel pipe Ø80 mm	Meter	5	450000	2250000
Foot step				
10 mm thick steel plate	Sheet	1	500000	500000
PP plate 3 mm	Sheet	1	300000	300000
Connection				
M10 nut	Seed	50	5000	250000
M10 bolt	Seed	50	5000	250000
Bearings	Seed	8	58200	465600
Support				
Iron paint	Cans	6	150000	900000
RD-260 welding electrode	Pack	1	150000	150000
Cement	Sak	5	150000	750000
Sand	Colt	0.5	400000	200000
Reinforcement Iron	Meter	5	200000	1000000
Gravel	Colt	0.5	300000	150000
Total				8165600

E. Production Plan

In production planning on tool design outdoor fitness type aerobic walker divided into two: determining the use of the machine and the treatment of each part [26]. It can be seen that the production planning is divided into 6 parts, where 3 parts are fabricated independently and 3 parts are purchased as shown in Table VI. The production classification can be seen in Table VII.

TABLE VI. PLANNING FOR THE ENGINEERING DESIGN

Part Number	Part name	Tapping	Counter boring	Drilling	Milling	Grinding	Shaping	Fillet	Chamfer	Others
1	Main Framework	N	Y	Y	N	Y	Y	Y	Y	
2	Foot Handle	N	Y	Y	N	Y	Y	Y	Y	
3	Foot step	Y	N	Y	Y	Y	Y	Y	Y	
4	Bearings									Purchased
5	M10 nut									Purchased
6	M10 bolt									Purchased

TABLE VII. CLASSIFICATION OF DESIGN PRODUCTION

Part		DFA Compl.[1]		Func. Analy.[2]		Er.[3]	Handling			Insertion								
No.	**Name**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**
1	Main Framework	1	1	N	H	Y	N	N	N	Y	Y	N	N	Y	Y	Y	Y	Y
2	Foot Handle	2	4	N	H	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	Foot step	2	4	N	H	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Bearings	1	4	Y	M	N	Y	N	N	Y	Y	N	Y	Y	N	N	Y	Y
5	M10 nut	25	25	Y	L	N	Y	N	N	Y	Y	N	N	N	N	N	N	N
6	M10 bolt	25	25	Y	L	N	Y	N	N	Y	Y	N	N	N	N	N	N	N

a. Number of Parts (Np)	j. Holding down required
b. Number of Interfaces (NI)	k. Resistance to Insertion
c. Part can be standardized	l. Obstructed access / visibility
d. Cost (Low / Medium / High)	m. Re-oriented Work Piece
e. Assemble part wrong way around	n. Screw / Drill / Twist / Rivet / Bend / Crimp
f. Tangle / Nest / Stick Together	o. Weld / Solder / Glue
g. Flexible / Fragile / Sharp / Slippery	p. Paint / Lube / Heat / Apply liquid or gas
h. Pliers / Tweezers / Magnifying Glass	q. Test / Measure / Adjust
i. Difficult to align / locate	

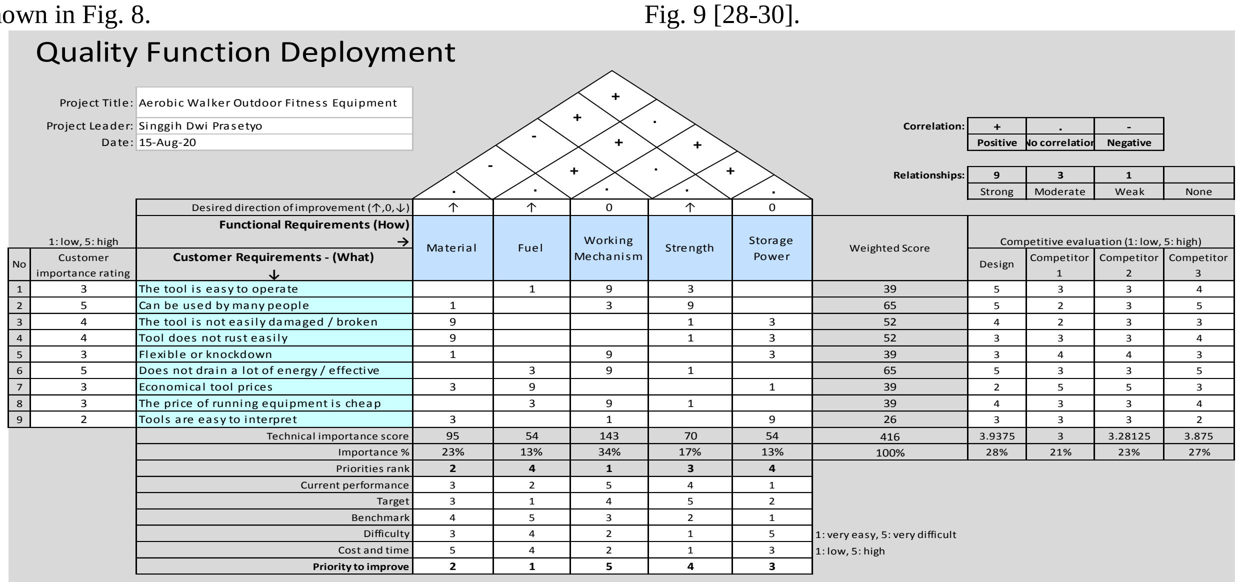
Note: [1] Compl is complexity; [2] Funct. Analy. is functional analysis; and [3] Er. is error.

F. House of Quality

The quality of product or tool design is evaluated using the house of quality system. Evaluation is to find out that the design product has a better value for consumer needs than other products [27]. The design results show that it has an added value on a strong frame, can be used by more than one person, and does not drain a lot of energy during operation. When compared with competitors or other products, the design has a better value of 3.9 as shown in Fig. 8.

G. House of Quality

The quality of product or tool design is evaluated using the house of quality system. Evaluation is to find out that the design product has a better value for consumer needs than other products. The design results show that it has an added value on a strong frame, can be used by more than one person, and does not drain a lot of energy during operation. During comparison with competitors or other products, the design has a better value of 3.9 as shown in Fig. 9 [28-30].



No	Customer importance rating	Customer Requirements - (What)	Material	Fuel	Working Mechanism	Strength	Storage Power	Weighted Score	Design	Competitor 1	Competitor 2	Competitor 3
		Desired direction of improvement (↑,0,↓)	↑	↑	0	↑	0					
1	3	The tool is easy to operate		1	9	3		39	5	3	3	4
2	5	Can be used by many people	1		3	9		65	5	2	3	5
3	4	The tool is not easily damaged / broken	9			1	3	52	4	2	3	3
4	4	Tool does not rust easily	9			1	3	52	3	3	3	4
5	3	Flexible or knockdown	1		9		3	39	3	4	4	3
6	5	Does not drain a lot of energy / effective		3	9	1		65	5	3	3	5
7	3	Economical tool prices	3	9			1	39	2	5	5	3
8	3	The price of running equipment is cheap		3	9	1		39	4	3	3	4
9	2	Tools are easy to interpret	3		1		9	26	3	3	3	2
		Technical importance score	95	54	143	70	54	416	3.9375	3	3.28125	3.875
		Importance %	23%	13%	34%	17%	13%	100%	28%	21%	23%	27%
		Priorities rank	**2**	**4**	**1**	**3**	**4**					
		Current performance	3	2	5	4	1					
		Target	3	1	4	5	2					
		Benchmark	4	5	3	2	1					
		Difficulty	3	4	2	1	5					
		Cost and time	5	4	2	1	3					
		Priority to improve	**2**	**1**	**5**	**4**	**3**					

Figure 9. House of Quality (HOQ) for the proposed aerobic equipment design

IV. CONCLUSIONS

Based on the house of quality, this tool has the highest product value compared to other types of competitors. From the design that has been made, the authors hope to help the wider community in the process of determining the manufacturing tool.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Z.A. and S.D.P.; methodology, J.H.C.; software, A.R.P.; validation, Z.A., J.H.C. and A.R.P.; formal analysis, S.D.P.; investigation, S.D.P.

The author suggests that readers can do and apply the making of tools according to the design results. The results of the manufacture can be tested at loads that are in accordance with the design basis, trials are carried out to be able to assist in the validity of this design. The design of an aerobic walker type outdoor fitness equipment using the design for manufacture and assembly method has been made. The basic concept of designing a tool for use by two people with an average weight of 80 kg operating at a maximum speed of 30 rpm. The design obtained from the tool is divided into 3 parts: the main frame, foot handle, and footrest. The material used is carbon steel with a bearing type of 6010. The results of tool design analysis have a better safety value determined by the safety factor and the age factor with 15 and 12128.52 hours respectively. The total price needed to make the tool is Rp. 8,165,600 based on the bill of material approach in Indonesia.

Resources, Z.A.; data curation, A.R.P. and J.H.C.; writing—original draft preparation, S.D.P.; writing—review and editing, A.R.P and Z.A.; visualization, S.D.P.; supervision, J.H.C. and Z.A.; project administration, Z.A.; funding acquisition, Z.A. All authors have read and agreed to the published version of the manuscript.

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