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Abstract. In this study, the conceptual design of a gravitational water vortex turbine has been developed. The conceptual turbine was designed to extract the energy from the house rooftop and generate the small power electricity using design principles. Through the concept of the House of Quality, the respondent requirements data were extracted to match with the scientific view in the design of the turbine. The data from the respondent was then linked to respond to the product characteristics by decomposing the function of the turbine. The divergence of three conceptual designs was being developed by cross-linking the part selection through the morphological chart. Of all designs, the final turbine design has been selected based on the concept of screening through the Pugh method and the concept of scoring of a weighted-decision matrix. Design 3 had been selected as the final product of this conceptual design study when the angle of the inlet opening is at 60°, the angle of pre-rotational is at 30°, with 3 number of blades, and when the body material is set as of polyvinyl chloride.

1 Introduction

Conceptual design is the design process that involves the identification of the problem, the product identification based on customer requirements, the comparison through benchmarking, the gathering of information, the concept generation, and the final selection stage [1]. Starting with the problem identification, the product design requirement is obtained from a customer survey [2], [3]. A House of Quality function is used to establish a relationship between the needs of the customer based on the product and the overall performance criteria and the functions of the product [4]. Then, a morphological chart was developed to produce ideas in a scientific systematic way. It is implemented to generate the design concepts [5] and combining all possible solutions [2] such as in designing a cashew sheller [6] and also in the methodological design of the Master student project [7]. Not even in the design of mechanical parts, this chart is also benefited in generating various PSS business model ideas [8]. The last conceptual design stage is the Pugh method. The key purpose of the Pugh method is to determine the best product ideas after the comprehensive design generation process is carried out [9]. This selection method had been applied on the design selection evaluation for an automotive application of a hydrostatic bearing pad state [10] and also being used in plant layout selection [11].

The gravitational water vortex turbine is a turbine used to extract energy from water and generate electricity. The water falls from the house rooftop and strikes the fan attached inside the turbine. The shaft at the turbine axis rotates and causes the generator to rotate while generates electric power. The application of turbines used in rainwater harvesting system from the rooftop is done by running the water stream through the downspout while passing through Pelton turbine through the experimental [12] and the simulation work [13, 14, 15]. Specifically zooming into the design area, a work done by F. A Ishola [14] had simulated the material selection on the pico Pelton turbine. This study revealed the capability of the aluminum alloy that outperform the steel and the plastic turbine in terms of the stress, displacement and the safety factor. In the same work area, the parametric study had investigated the aluminum alloy Pelton turbine efficiency between 300 W to 1000 W [15] through FEA study.

The design of a gravitational water vortex turbine is crucial since this kind of turbine is only applied on the flowing river stream where the stream velocity is high. Up to the author's knowledge, the FEA study of this kind of turbine has never been done for rooftop water harvesting systems. Hence, the purpose of this study is to investigate the structural analysis on the capability of the gravitational turbine to be applied for rooftop rainwater harvesting system.

2 Methodology
This section shows the design principles that have been carried out throughout the conceptual design processes of the turbine.

2.1 Survey
To gather the information on the turbine design, a survey was carried out among mechanical engineering students and employees. The respondents have the engineering background. This survey consists of three sections which are the demographic data, the views of the respondent on the design of the gravitational force turbine for rooftop application, and the rate of the customer needs to be based on product characteristics.

2.2 House of Quality
The House of Quality method was introduced to quantify the relationship between the specific criteria and the engineering specification [4]. By using the HOQ method, the customer requirements and the engineering characteristic can be associated with each other to get the relationship between both criteria.

2.3 Morphological Chart
A morphological chart is a method that visually captures the functionality of the product and exploring any alternative means and combinations in achieving that functionality. Different procedures are drawn up which are being utilized to execute the listed functions. They are used as visual aids to generate different ideas.

3 Results
This section describes the results of the conceptual design concept on designing the turbine.

3.1. Flow Process
The workflow process in this study is shown in figure 1 which starts from the respondent surveys till the final selection of the turbine design.
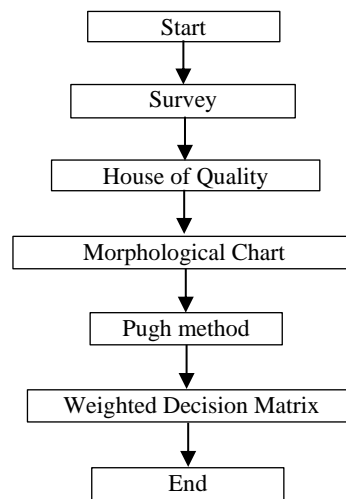
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│    Start    │
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│ House of Quality │
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│ Morphological Chart  │
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┌─────────────┐
│ Pugh method │
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│ Weighted Decision Matrix │
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│     End     │
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Fig. 1. Flowchart of the work process.

3.2 Respondent Requirements Analyses

The majority of survey participants (n = 63.3%) were men. Most participants (n = 80%) were mechanical engineering students. All respondents have general knowledge about a turbine and 40% of the total respondent have specific knowledge about the gravitational force turbine. A majority of participants (n = 90%) agreed that the turbine is powerful, (n= 96.7%) safe to operate, (n= 83.3%) high lifespan and (n= 83.3%) have high endurance limit.

3.3 Product Design Specification (PDS)
The PDS is a system that was created at the starting of the design process during the problem description. This shows the obligations that need to be met with the plan objective. The conditions for identifying a suitable gravitational force turbine are based on these points:
i) Performance - The gravitational force turbine must be capable to generate power from the rainwater that falls on top of a rooftop.
ii) Material - The material must be corrosion-resistant material so that it will not rust or corrode due to rainwater. Hence, the product is long-lasting and worth the price.
iii) Not easily damage - The turbine is cone-shaped based and seemed to be unstable due to the connectivity with the rotating part and high stability point. Hence, the product is designed to be stable in a stand at the optimum angle.
iv) Safety - The gravitational force turbine must be safe to be used because it involves a rotating machine.

3.4 House of Quality
The information that consists in the House of Quality as shown in figure 2 matches the respondent requirement and engineering characteristic of the gravitational force turbine. To match with the turbine power requirement as specified by the respondent, the turbine should be designed accordingly based on several parameters. This had been identified as inlet opening angle, pre-rotational blade angle, and number of the blade within the cone section. Moreover, the respondent requires a long lasting product that not easily be damaged. This corresponds to the material selection in this study, and the structural analysis that will be discussed for further work.
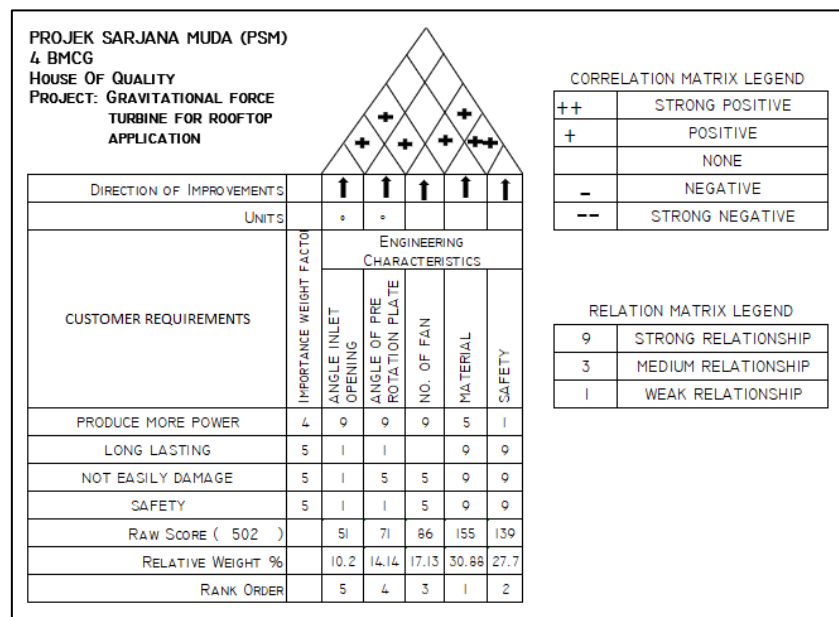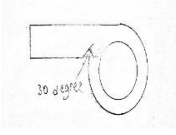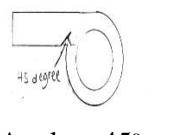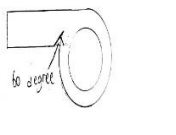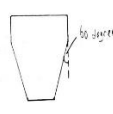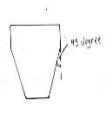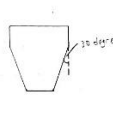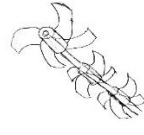
Fig. 2. House of Quality.

3.5 Morphological Chart

The morphological chart as shown in table 1 decomposes the characteristic of the turbine into four main categories, such as the i) angle of the inlet opening, ii) angle of the pre-rotational plate, the number of the blades used in the basin, and the iv) materials of the turbine casing. The infeasible concepts are rejected to reduce the combinatorial concept. In this conceptual design, the function of the turbine is an important matter rather than the aesthetic value. Hence, this chart presents the significant parameters to be looked into. The angle of inlet openings and the pre-rotational plate are chosen in the range of 30º, 45º, and 60º. The number of blades is 1, 2, and 3 while the material chosen are carbon fiber, aluminum, and polyvinyl chloride (PVC).

Table 1. Morphological chart.

Function	Solution		
	1	**2**	**3**
Angle of inlet opening (A)	Angle = 30º	Angle = 45º	Angle = 60º
Angle of pre-rotational plate (B)	Angle = 60º	Angle = 45º	Angle = 30º
Number of blade (C)	One blade	Two blades	Three blades
Materials (D)	Carbon Fibre	Aluminium	PVC

3.6 Conceptual Design

Figure 3 shows the conceptual design of Sketch 1, Sketch 2, and Sketch 3. Sketch 1 conceptual design is the combination of functions between A1, B1, C1, and D1. This design concept uses a 30° angle of inlet opening for the water to flows in, and 30° angle of the pre-rotational plate to produce the water vortex inside the conical plate. It consists of one fan and uses carbon fiber as the body material. Sketch 2 conceptual design consists of functions A2, B2, C2, and D2. The idea of the design uses a 45° angle of the inlet opening, and 45° angle of the pre-rotational plate. It consists of two fans and an aluminum body. Meanwhile, sketch 3 combines the functions of A3, B3, C3, and D3. This design uses a 60° angle of the inlet opening, and 30° angle of the pre-rotational plate. It uses three fans and the material usage of the body is PVC.
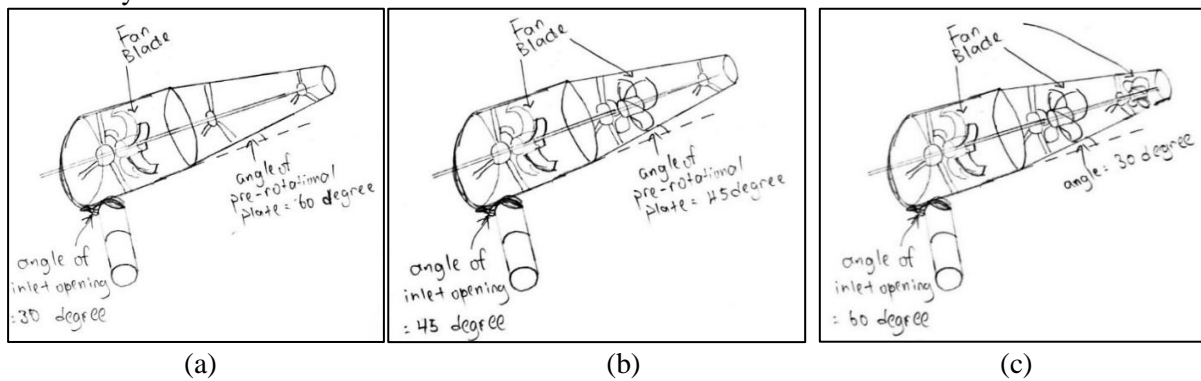

(a)   (b)   (c)

Fig. 3. Conceptual Design of (a) Sketch 1, (b) Sketch 2 and (c) Sketch 3

3.7 Design Selection

Based on the Pugh method and Weighted Decision matrix as shown in tables 2 and 3 respectively, it shows that design 3 is the best design for the vortex gravitational force turbine. This is resulted from the highest score for design 3 as compared to the design 1 and 2. Therefore, concept design 3 has been selected as the final design for further consideration and analysis.

Table 2. Pugh Method.

Criteria	Conceptual Design		
	1	**2**	**3**
Faster water velocity	-	=	+
More water vortex produces	-	=	+
Safe to use	=	=	=
Lightweight	+	=	-
Easy to use	=	=	=
Produce more power	-	-	+
Long-lasting	=	=	=
Sum of '+'	1	0	3
Sum of '-'	3	1	1
Final score	**-2**	**-1**	**2**

Table 3. Weighted decision matrix.

0	1	2	3	4
Unsatisfactory	Just tolerable	Adequate	Good	Very good

Criteria	WGT	Conceptual Design					
		1		**2**		**3**	
		Rate	WGT Rate	Rate	WGT Rate	Rate	WGT Rate
Faster water velocity	0.18	2	0.36	3	0.54	4	0.72
More water vortex produces	0.18	2	0.36	3	0.54	4	0.72
Safe to use	0.20	2	0.4	3	0.6	4	0.8
Light weight	0.1	3	0.3	3	0.3	2	0.2
Easy to be used	0.09	2	0.18	2	0.18	2	0.18
Produce more power	0.15	1	0.15	3	0.45	4	0.6
Long Lasting	0.1	2	0.2	4	0.4	3	0.3
Total	1.00		1.95		3.01		3.52
Rank		**3**		**2**		**1**	

4 Conclusion

The study investigated the process flow in design principles of gravitational water vortex turbine. The method approaches the step-by-step technique to achieve the main objective of the study, to conceptually design the turbine. The survey conducted had been analyzed to determine the product specifications that in line with the respondent requirements. These included the angle of the inlet opening, the angle of the pre-rotational plate, the number of the fan within the basin, the basin material, and the safety of the system. Based on the data collected, the House of Quality had been developed. The rank score showed that the angle of the inlet opening scored the highest while the material of the basin scored the lowest value. This relates to the hierarchical significance of each parameter. This also leads to the divergence of turbine designs that had been sketched through the morphological chart. The final selection of the design had been performed using the concept of screening and scoring method. Through the Pugh method and weighted decision matrix, Design 3 is the final selected design at 60° and 30° angle of the inlet opening and pre-rotational angle respectively, 3 number of blades used and polyvinyl chloride body material to produce the highest power and matches the customers need.

Acknowledgments

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