Design and analysis of sustainable paper bicycle

Taufik Roni Sahroni and Januarnasution
Industrial Engineering Department, Faculty of Engineering, Bina Nusantara Jakarta, Indonesia 11480
Email: taufik@binus.edu

Abstract. This paper presents the design of sustainable paper bicycle which describes the stage by stage in the production of paper bicycle. The objective of this project is to design a sustainable paper bicycle to be used for children under five years old. The design analysis emphasizes in screening method to ensure the design fulfill the safety purposes. The evaluation concept is presented in designing a sustainable paper bicycle to determine highest rating. Project methodology is proposed for developing a sustainable paper bicycle. Design analysis of pedal, front and rear wheel, seat, and handle were presented using AutoCAD software. The design optimization was performed to fulfill the safety factors by modifying the material size and dimension. Based on the design analysis results, it is found that the optimization results met the factor safety. As a result, a sustainable paper bicycle was proposed for children under five years old.

Keywords: Design, analysis, sustainable, paper, bicycle

1. Introduction
The development of sustainable product has been widely discussed among society. At the moment, people are trying to approach and experience in the implementation of design for environment (DFE). Sustainable product has become a tremendous impact to the society life in future due to several reasons such as global warming, the use of plastic bag, pollution, and waste from the unused material due to mass production in manufacturing industries. Furthermore, the society is facing the biggest issues related in developing the sustainable product.

Several countries have introduced the sustainable awareness using an electrical bicycle as a sustainable transport consumption behavior and socio-technical transitions in Nanjing, China [1] and recently research was conducted by Aljoufie in 2017. The author assessed the attitude toward bicycle use and the perception of obstacles for using bicycle for different age groups of Jeddah city residents [2]. Another research was studied in Beijing, where the increasing city size and urban expansion were great challenges to cycling systems [3]. The sustainable awareness from various mass media sources and the general public was studied in Italy and found that some respondents overlap in perceiving of using bike in the city [4]. Although, the sustainable awareness of using bicycle had similar in several cities, there is still need to be further studied in society perceiving of sustainable paper bicycle.

The technology in developing a sustainable product has been widely discussed in many countries. The authors were illustrated the usage of the method’s problem induced path in mobility as one area of human living, based on three surrounding field scenarios for bicycle mobility in Berlin, technology systems for bicycle design, operation and their repair in self-help workshop [5]. One of the most appropriate approaches in technology was introduced by Chardon etal., (2017), that causal variables...
associated with higher bicycle sharing system performance [6]. Another system was explained to explore
the reasons that Amsterdam and Wuhan have gone in different directions in implementing bicycle as
main city transportation [7]. The technology tracking system was gathered the data from 150 countries
of household bicycle possession and ownership values [8]. However, there is still room to be studied the
perception of sustainable bicycle from user in Indonesia.

The safety in developing the bicycle has play important aspect in order to ensure the bicycle suit the
standard specifications and customer requirements. There are several studies have been conducted in
safety impacts of bicycle structures [9], coupling model for bicycle sharing [10], and hydraulic disc
brakes [11]. The safety of product has influence the overall of production cost due to related with
material selection, dimension, ergonomic, and the complexity of the product. Most of the cited authors
have been focused in metal basis for developing the proposed bicycle.

In general, the development of a sustainable paper bicycle should follow the safety requirements.
Therefore, this project tries to fill the gap of research that has been conducted by other researchers to
focus on the design analysis of a sustainable paper bicycle for children under five years old. This project
is designed by using waste paper as different perspective in low cost and recycle the waste.

Sustainable paper bicycle is a new thing in our country. By creating bicycle from waste paper could
develop further the creativity level from engineers in the country. There are several considerations in
developing a sustainable paper bicycle such as environment, green manufacturing and low cost. These
elements must be taken into account to ensure paper bicycle created to meet the requirements and user-
friendly environment.

2. Materials and Method

In this phase, the process begin with draw bicycle 2D Layout. For 3D rough layout, the authors generate
the cluster design and estimate the load distribution for the model. The estimation of the load distribution
is performed in order to run the design analysis for the critical part. This phase then proceed to 3D detail
layout which need to generate the 3D detail modelling and conduct the analysis for the modelling part.
Figure 1 shows the flow chart of development process for this project.

![Flow chart of development process](image)

The process begin with sketched on the square board and on the hollow rod followed the specific
dimension. Next stage, proceed to start the cutting square board and hollow rod by following the sketches
figures. Then the square board was cut layer by layer by following the drawing that drawn by using CAD
software. Next process, start glued the cutting part layer by layer and clamp them with the vise in order
for part reinforcement. After Glued all the parts and renfoced with some resin, then all the parts need to
assembled followed cluster by cluster. The most critical part need to be done first in order to test the
ability of the parts toward the given load. After finish assembled all the parts, the bicycle need to be
touch-up in order to give it look attractive for children under five years old.
3. Results and Discussion

The result of the project will focus on the character of the paper, concept evaluation, and design analysis. Concept selection is the process of evaluating concepts with respects to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts and selecting one or more concepts for further investigation, testing or development. All the 5 concepts need to give the rating based on the design. The point given based on the characteristic for every bicycle concepts and after rating all the concepts, the number of (+), (-) and (0) need to sum up to identify the most higher ranking. The three higher ranking in this concept screening method was Concept 1, Concept 2 and Concept 3 which come out with 12, 10 and 9 points for each. The concept that has the highest ranking is the concept that fulfils the criteria for the paper bicycle. Table 1 lists the screening method and collected from the designers in average as part of development process.

| Selection criteria             | 1 | 2 | 3 | 4 | 5 |
|-------------------------------|---|---|---|---|---|
| Functionality                 |   |   |   |   |   |
| 1) Lightweight                | 0 | + | + | - | - |
| 2) Fits different bars        | + | + | + | + | + |
| Ergonomics                    |   |   |   |   |   |
| 1) Low force to secure        | + | 0 | + | + | + |
| 2) Seat adjustable            | - | - | - | - | - |
| 3) Comfortable                | + | + | 0 | 0 | - |
| 4) Body posture               | + | + | + | + | 0 |
| 5) Corner handling            | + | + | + | + | 0 |
| 6) Handle grip                | + | 0 | + | + | - |
| 7) Brake position(leg/hand)   | - | 0 | 0 | 0 | 0 |
| 8) Seat shape                 | 0 | - | + | + | 0 |
| Durability                    |   |   |   |   |   |
| 1) Longevity                  | + | + | + | + | + |
| 2) Frame structure            | + | + | + | + | 0 |
| 3) Rim durability             | + | + | 0 | + | 0 |
| 4) Wheel thickness            | + | + | + | + | 0 |
| 5) Number of wheel            | + | + | + | + | 0 |
| 6) Handle grip                | + | + | 0 | 0 | 0 |
| 7) Paddle                     | 0 | + | 0 | 0 | 0 |
| Easy to use                   |   |   |   |   |   |
| 1) Easy comfortable to grip   | + | + | + | + | 0 |
| Other                         |   |   |   |   |   |
| 1) Material usage             | + | + | + | - | - |
| Sum’s of (+)                  | 14| 13| 12| 11| 5 |
| Sum’s of (-)                  | 2 | 3 | 3 | 3 | 6 |
| Sum’s of (0)                  | 3 | 4 | 6 | 5 | 8 |

Table 1. Screening Method

Figure 2 shows the selected design to be further developed and analysed using CAD software.
For this concept, this bike also has three wheels, which two wheels at the back and a wheel at the front. The front wheel of this bike is designed much bigger than the rear wheels. The body posture of the rider need to lean a little backward. The structure of this design is very simple and easy to do the joining. The front wheel is bigger than rear wheels so that the force needed to move the bicycle is lower.

The composition of paper affects reproducibility based on age, lesser extent and its legibility. The presence of ground wood pulp causes yellowing of the paper with age, the effect increasing with an increase in the percentage content of ground wood pulp. Contrast between the printed characters and the paper is reduced with age and yields poorer copies upon reproduction. It is recommended that if through economic considerations the presence of ground wood pulp is unavoidable it be present to no more than 30%. Some types of paper become brittle with age and physical handling during reproduction necessitates that the use of such paper should be avoided. The strength and folding endurance of the paper should remain substantially independent of age. This paper will affect ink drying. Acidity is the main retarder of drying. A pH below 4.5 is able to cause serious troubles, particularly in humid weather whereas papers having a pH between 4.5 and 6.0 rarely give some trouble. In coated papers, the base acidity has little effect; it is the coatings that determine how fast paper will dry. The design has done the analysis by using CAE Analysis on every cluster by using the given material properties such as Mass Density = 756 kg/m$^3$, Elastic Modulus (Modulus Young) = 2348 MN/m$^2$, Rapture Stress= 14.46MPa, Poison Ratio= 0.3 and lastly Factor of Safety = 2.0.

Figure 3 shows the pedal design before optimization with Safety factor: 5.66 and maximum stress: 2.557MN/m$^2$. After optimization Safety factor: 2.87 and maximum stress: 5.033MN/m$^2$. For pedal analysis the load is 100N and after optimization, the thickness of the pedal has been reduced from 27.6mm to 23mm.
Figure 4 shows the rear wheel design. The design analysis is conducted using the load of 559.17 N and after optimization, the thickness of the rear wheel has been reduced from 25.4 mm to 23 mm. The design before optimization is presented with safety factor: 151.48 and maximum stress is 0.09546 MN/m². After design optimization, safety factor is 7.13 with maximum stress is 2.028 MN/m².

![Figure 4. Rear wheel design](image)

(a) Before  
(b) After

Figure 5 shows the rear wheel design. Before optimization, the front wheel design has safety factor of 196.44 with maximum stress of 0.07361 MN/m². After design optimization, front wheel design has safety factor of 7.59 with maximum stress of 1.906 MN/m². For front wheel analysis, the load is 472.78 N and after optimization, the thickness of the front wheel has been reduced from 25.4 mm to 23 mm.

![Figure 5. Front wheel design](image)

(a) Before  
(b) After

Figure 6 shows the seat design. Before optimization, seat design has safety factor of 4.5 with maximum stress of 3.21 MN/m². After optimization, seat design has safety factor of 1.9 with maximum stress of 7.546 MN/m². From the table 2.4, the load is 745.56 N and after optimization, the thickness of the seat has been reduced from 30 mm to 23 mm.

![Figure 6. Seat design](image)

(a) Before  
(b) After
Figure 7 shows the handle design. Before optimization, the handle design has safety factor of 16.85 with maximum stress of 0.8584 MN/m$^2$. After design optimization, the handle design has safety factor of 8.53 with maximum stress 1.696 MN/m$^2$. For handle analysis the load is applied for 100N and after optimization the size of the Handle was reduced from 51mm in diameter to 38.2mm diameter.

(a) Before  
(b) After  
Figure 7. Handle design

4. Conclusion
The design and analysis for sustainable paper bicycle was presented using CAD software. The screening concept was evaluated from alternatives design based on the criteria of functionality, durability, ergonomics, and ease of use. From the screening method, the best design was selected for further analysis. The static structure analysis was performed for pedal, front and rear wheel, seat, and handle were presented using AutoCAD software. Based on the design analysis results, it is found that the optimization results met the factor safety. Furthermore, it is feasible to develop a paper bicycle from waste paper. The impact of this study to the society is to create awareness of sustainable product from waste paper. As a result, a sustainable paper bicycle was proposed for children under five years old.

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