

A Foldable Product: Implementing Techniques of Product Design Process

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Abstract

The main concept of product design is an understanding of the end-user, for whom the product is being created. Foldability and mobility are examples in the engineering design process to create and improve customer value in product design. This paper presents a construction and implementation of the design of a foldable bicycle that helps to incorporate foldable capacity and personalization in a regular product design. A foldable bicycle is designed to fold into a compact form, facilitating transport and storage. When folded, the cycle can be more easily carried into buildings, on public transportation and more easily stored in compact living quarters. In the primary stage, customer survey was carried out for the purpose of understanding and prioritizing customer needs. To compare with the technical and customer requirements, Quality Function Deployment (QFD) was performed using the House of Quality (HOQ). Functional Decomposition was used using the Black Box Diagram to the process of resolving a functional relationship into the constituent parts of the product. Design of the parts, assemblies are developed in Solid works with stress analysis which brings about the foldability, compactness and space utilization of the cycle.

Keywords

Product design, Foldability, Quality Function Deployment (QFD), Functional Decomposition, Stress analysis.

1. Introduction

The product design process is the set of strategic and tactical activities, from idea generation to commercialization that is used to create a product. It is an efficient way to deal with conceptualize and assess thoughts, transforming them into tangible innovations and items. It is a dynamic procedure, wherein the engineering sciences are applied to change over resources ideally to meet an expressed target. The fundamental elements of the design process are the establishment of objectives and criteria, comparison, analysis, development, testing and evaluation. Further, it is essential to include a variety of realistic constraints such as monetary variables, safety, reliability, aesthetics and social effect.

The stages in the product development process are classified based on the type of technical activities performed in it. It analyses the limitation in the existing product, from which the opportunity to develop a new design is created. The second phase, conceptual design deals with the generation of as many solutions as possible to evaluate it to select the best concepts (Muthiah and Ramadass, 2018). Transport has been one of the foremost important issues to be addressed within the present-day situation and for overcoming the transportation problem, an idea is developed to design and fabricate a foldable bicycle, which is light, rigid, safe, easy to handle and maintain. The primary purpose of folding a cycle is to increase its portability. The foldable bicycle is designed to fold down into a more compact form, making it easier to carry, store away or fit into areas rather than a regular bicycle and thus allow greater flexibility. It varies in the actual folding methods and components. According to (Muthiah and Ramadass, 2018), the need for a foldable bicycle arises from the market survey which reveals that the normal bicycles that are available in the market are of heavyweight, less compact and unable to be carried to various places during traveling by a commuter. Foldable bicycles have a completely different geometry than conventional city bicycles, which proves to be a problem during the design process. A different geometry means different critical structural parts, which have to be dimensioned for the maximum safety of the rider. This can be achieved by following a standard or by knowing the loads on the bicycle (Pimat et al., 2011).

The basic principle of foldable bicycle is the side-to-side alignment of the front and rear wheels, produced by the action of one or more hinges in the frame. Design variables such as the number of pivots and the direction of the pivot axis differentiate various types of folding mechanisms. Commuters who travel by bicycle and then cover part of the

commute through other modes of public transportation should be able to fold and unfold a bicycle repeatedly. Thus, the ease with which a bicycle could be folded directly influences user satisfaction. This ease of folding is closely related to the type of folding mechanism, which is determined by the number and directions of pivot axes (Roh et al., 2018).

The aim of this paper is to apply the product design process to introduce and develop the design of foldable bicycle which can be moved and stored easily in lesser space. In section 2, the relationships between the customer needs and design requirements are described using House of Quality (HOQ), a phase of Quality Function Deployment (QFD). In section 3, the functional decomposition of the product has been performed to express the functional relationships into different parts of foldable bicycle. Finally, the design analysis of foldable bicycle is described in section 4.

2. Implementation of Quality Function Deployment on Foldable Bicycle

The Quality Function Deployment process starts with collective input from potential customers, is a structured approach to define customer needs or requirements and transferring them into specific plans to meet those needs. QFD employs a cross-functional team to determine customer needs and translate them into product designs through a structured and well-documented framework (Karsak et al., 2002). House of Quality (HOQ) is the primary metrics for QFD. According to (Hauser & Clausing, 1988), the HOQ is a kind of conceptual map that provides the means for inter-functional planning and communications.

2.1 House of Quality

The House of Quality (HOQ) is a voice of customer analysis tool and a key component of the Quality Functional Deployment technique. House of quality is a tool to translate what the customer wants into products or service that meet the customer wants in terms of engineering design values by way of creating a relationship matrix. Complexity of product development is the major reason to employ House of Quality (HOQ). The House of Quality (HOQ) is applied in the workstation in order to diagnose the relationship matrix between the voice of customers (VOC) and technical requirements. The development of proactive product is more reliable than the development of reactive product or designing and manufacturing products that delight customers and fulfill their unarticulated desires. For this study, VOC is discerned by a qualitative analysis. The targeted customers were identified and the VOC was captured by surveying with the help of relative questionnaire. The design requirements were resolved by a tree diagram. Technical requirement for this study includes Mechanical Design, Physical Aspects, Economical Aspects where voice of customer (VOC) includes Light weight, Comfortability, Easy to Use, Aesthetics, Durability, Joint Strength, Portability, Functionality, Foldability, Variation in Sprocket. Design flow for House of Quality (HOQ) start with customer attributes portion of matrix (horizontally) and Engineering characteristics matrix (vertically). Co-relationship matrix is assigned as a form of triangular shaped roof where in the central portion there remains relationship matrix. Competitive Technical Analysis and Absolute importance, Relative Importance & Target were also analyzed in House of Quality (HOQ). Following figure (Figure 1) represents the desired HOQ including the VOC and the technical requirements.

●	Strong (9)
○	Moderate (3)
■	Weak (1)
Blank	No Relationship

+	Positive, Supporting
-	Negative, Tradeoff
++	Strong Positive
--	Strong Negative

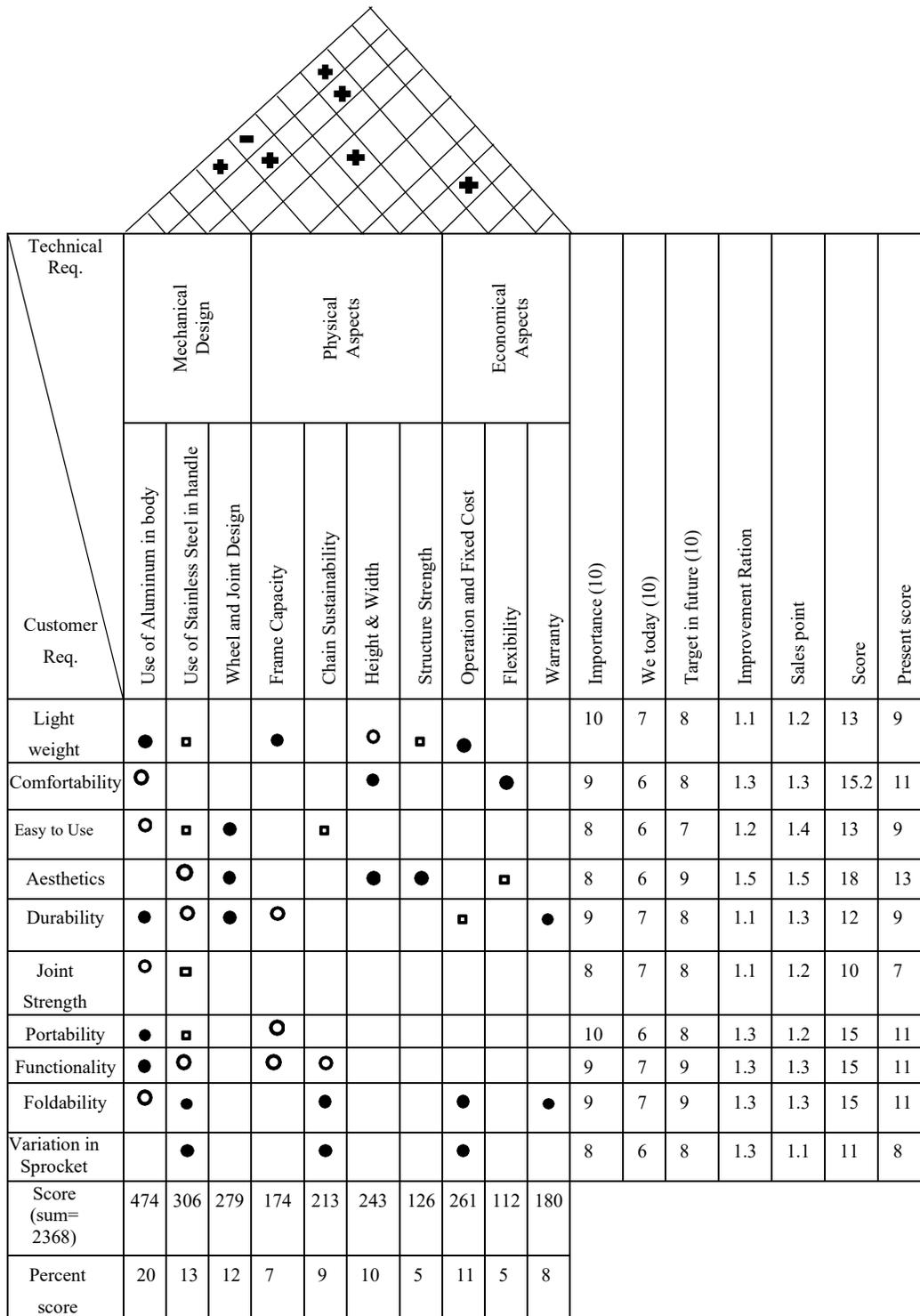


Figure 1: House of Quality for Workstation

A clear determination about how much emphasis is needed to be applied in which customer or design requirements. For designing the product, it would be conceivable to prioritize essential features compared to each other customer requirements or design requirements.

3. Implementation of Functional decomposition on Foldable Bicycle

Functional decomposition is a term that is used to describe a set of steps in which it breaks down the overall function of a device, system, or product into its smaller parts. This is usually accomplished through thoughtful analysis and discussions of product information and the result is a chart that describes the problem and solutions in increasing detail. It dissects the whole product into its components and their respective functions. The prime objective of this is to get a clear vision of all the functional requirements of the product and to search for further development of the design.

According to (Eck et al., 2017), functional decomposition is considered as an important technique in engineering design that is required in the initial conceptual phase of the design process. In the research of (Stone et al., 2000), the sub-functions of functional decomposition are related by the flow of energy, material, or information passing through the product to form a functional model, known as a functional structure. In another research, Pahl and Beitz provided an overview of such a functional decomposition process. (Yu et al., 2012) described it as a connecting link which passes and generates design information.

3.1 Black Box Model of Functional Decomposition

Black Box model is an approach to view the function of the product in terms of its input and output with a suitable figure. This model develops a relationship between customer requirements and the basic function of the product. Each input and its respective output represent one of the customer needs.

There are generally three types of input and corresponding output in a black-box. They are:

- Energy flow
- Material flow
- Information flow

Black box model of the foldable bicycle is given below:

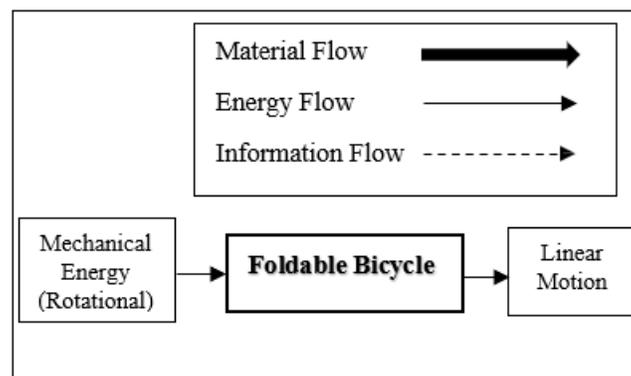


Figure 2: Black Box Model of Foldable Bicycle

3.2 Component Hierarchy

Component Hierarchy describes the relationship between content components of a product in terms of structure and function. It divides the components into various major groups and subgroups to relate them. It grounds the basis of the design perspective of a product. Component hierarchy of foldable bicycle is shown below:

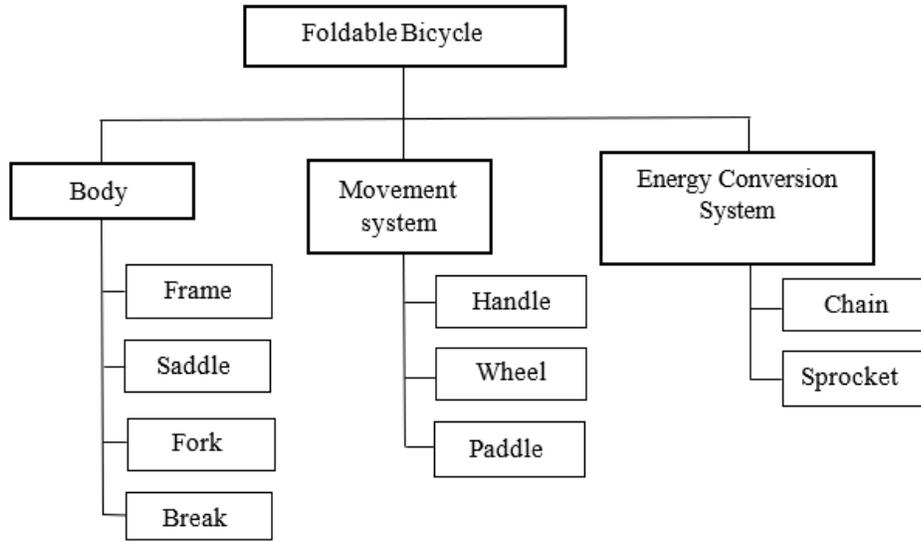


Figure 3: Component hierarchy of Foldable Bicycle

3.3 Cluster Function Structure

The cluster function structure shows the material, energy, and information flow with detail working procedures and how they relate to each other. The cluster function structure for foldable bicycle is given below:

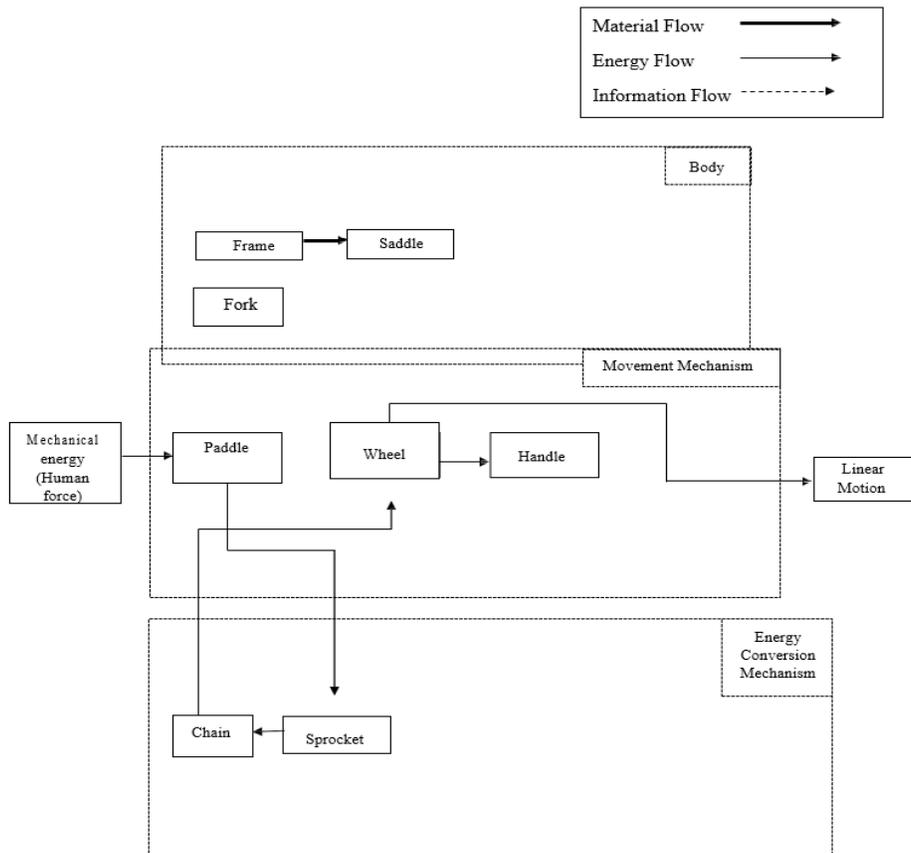


Figure 4: Cluster function structure of Foldable Bicycle

From the functional decomposition analysis, we have got an idea about how the product works. Black box model summarizes the whole material, energy, and information input and output of the product while functional decomposition makes it easier to understand a complicated system, its components, the interactions and interfaces and is a useful tool in providing requirements insights for both analysis and design. The component hierarchy for different mechanisms shows all the components in each of the mechanisms. And the cluster function structure shows the flow of material, energy, and information of the whole product as detail as possible through a pictorial view.

4. Design Analysis for foldable bicycle

Design Analysis represents an approach for establishing an intelligent support system in order to design a product through managing variety. For simulating physical behavior on computer, Design Analysis is a cogent software technology which can minimize or even eliminate the need for physical prototyping and testing. The interpretive tool is applied to visualize the hierarchy of component interactions within a product. This approach represents the design priority and related design dimensions for helping designers to create variants design solutions in a product for different market requests. Engineers can use a design analysis to predict the physical behavior of just about any part or assembly under loading conditions.

According to (Silva & Chang, 2002), the complexity of the design changes is multiplied when the product design involves multiple engineering disciplines. Very often, a simple change in one part may propagate to its neighboring parts, therefore, affects the entire product assembly. Both parts and assembly must be regenerated for a physically valid product model, at the same time, the regenerated product model must meet designer's expectations. When a product is being developed in a Concurrent Design and Manufacturing (CDM) environment, the design changes are usually implemented first by altering geometry of the product represented in computer-aided design (CAD) solid models. If the product solid model is not parameterized properly, the changes in geometry often lead to invalid parts or assembly. At the part level, the changes may yield a solid model with invalid geometric features if it is not properly parameterized. In this case, the entire product assembly is in vain. Even when individual parts of the product are regenerated correctly, parts may still penetrate to their neighboring parts or leave excessive gaps among them, if the solid model is not properly parameterized at the assembly level.

Figure 5, 6 represent different assemblies of the bicycle and Figure 7, 8 show the final unfolding and folding states of the product respectively.



Figure 5: Body

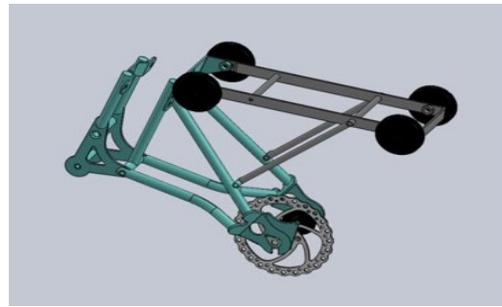


Figure 6: Rear Gear Assembly



Figure 7: Unfolding State of bicycle

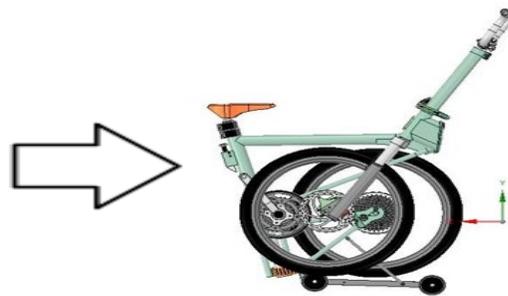


Figure 8: Folding State of bicycle

4.1 Stress Analysis

Stress Analysis is an engineering discipline that uses many methods to determine the stresses and strains in materials and structures subjected to forces. Stress Analysis provides the goal of being the design of structures that can withstand a specified load, using the minimum amount of material or that satisfies some other optimality criterion. This analysis has provided the idea of how reliable the product will be when various ranges of load applied on the structure.

4.2 Stress Analysis of frame

This study experimentally investigated cycle frame loads and verified analytical load cases applied to vehicle design. In Figure 9, load have applied separately on the frame. The upper frame could take more load than the other part of the frame structure. The loads applied are 490N (50kg).

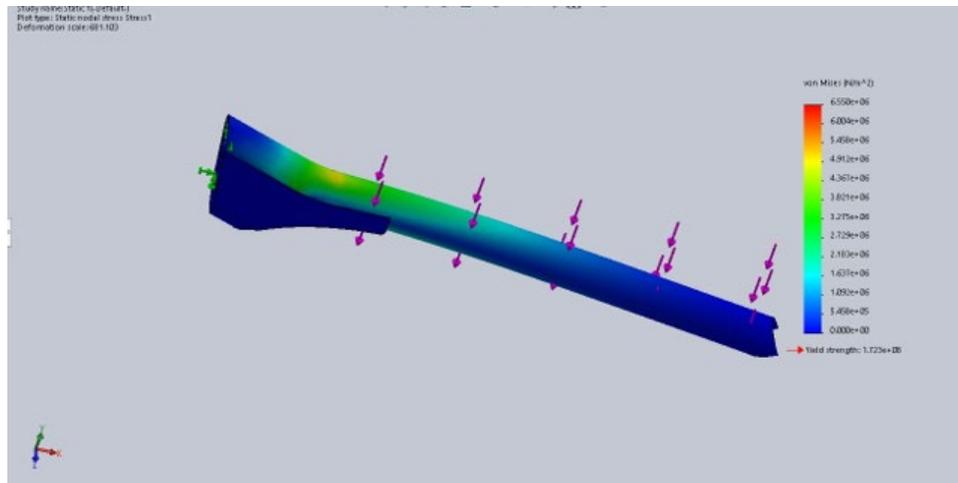


Figure 9: 490 N load applied on the upper part of the frame

4.3 Stress Analysis of fork

Bicycle fork is the part that holds the front wheel and typically consists of two blades which are joined at the top by a fork crown. The load applied would be lesser compared to the seat. In Figure 10, we have applied 98N (10 kg) force for analyzing the stress.

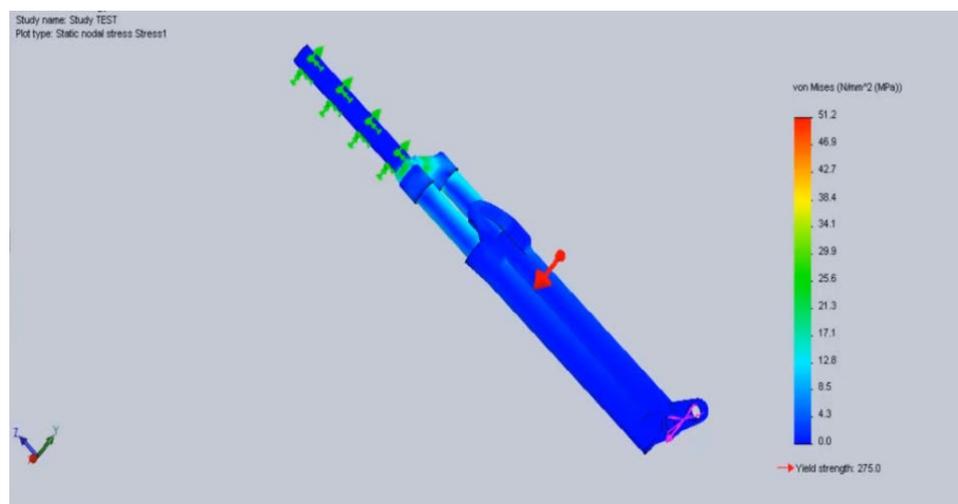


Figure 10: 98 N load applied on fork

4.4 Stress Analysis of wheel

For carrying the load, a total of 2 wheels remain in our design and due to symmetry, any load will be equally distributed between the wheels. In Figure 11, we have applied 588N (60 kg each) on the wheel for analyzing the stress.

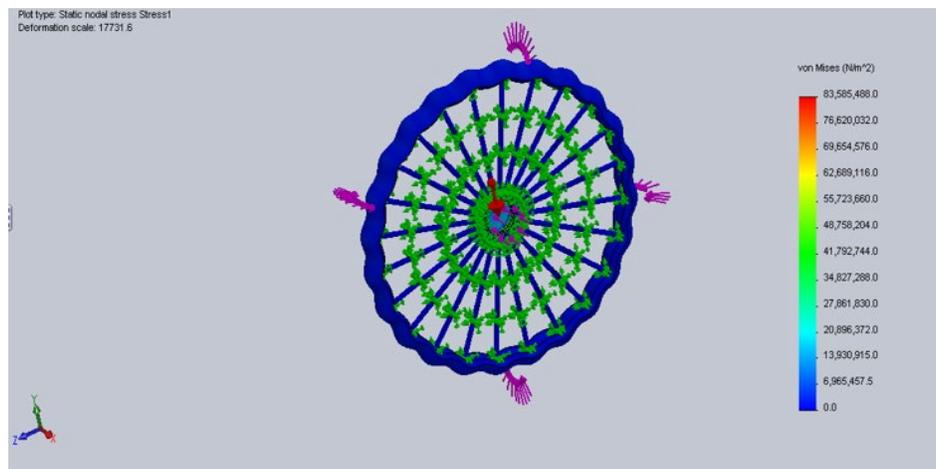


Figure 11: 588 N load applied on wheel

5. Conclusion

Product design and development reverberate customer choice on the product and so the process should be happening according to the choice of customers. The aim of this paper is to reflect both customers' desires while developing a product and reduce space consumption. The design parameters have selected from the views of customers which makes the product more acceptable for the customers. This design can further be modified by applying ergonomic and economic analysis of the bicycle and also by adding more feature to improvise its foldability and functionality.

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