DESIGN AND OPTIMIZATION OF MOBILITY ATTACHMENT ON JANITOR CART IN CAMPUS TECHNOLOGY UTEM

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Ahmad Afiq Zakwan Bin Zulkifli

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A thesis submitted
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DEDICATION

I dedicated this final year project to my loving and supportive parent Zulkifli bin Husin and Nor Azlina binti Abdullah who have always supports my journey to achieve my dreams. Your unvaluable faith in me has been my strength of my success, I am sincerely grateful for your guidance and love. To my fellow friends, who have give supports in mentally and morally throughout my academic journey, I fully appreciate your constant supports and encouragement. Lastly, to honored my supervisor, Mohd Harris Fadhilah Bin Zainudin and all staffs in UTeM. Thanks to all my friends for their morally support throughout this research. Thankyou for all of your guidance along in preparing this project.

ABSTRACT

This final year Barchelor Degree Project outlined the background of the project on " Design and Optimization of Mobility Attachment on Janitor Cart in Technology Campus, UTeM ". The challange on the mobility of the janitor cart where the disadvantage of disability to go up to second floor in building setting which is by using stairs. This project was be done by implementing suitable methods which are by Pugh Method in selecting design. It ensure that the selected concept is align with the needs of this project. House of Quality (HOQ) analysis was also used which from the criteria analysis it was found that the design meets with user requirements wanted the design to be. Using Finite Element Analysis is to determine the simulation in analyzing design to obtain the Von Mises Stress and Displacement on the design. In this project, the design of the attachment was carried out using a Computer-Aided Design (CAD) software where to obtained an accurate and precious illustration visual for the attachment on the cart. The design of the attachment has been developed for comfortability uses. Optimization process using Topology Optimization Method used to minimise mass by maintaining optimum strength of the design. The safety factor of the design determined by analysis which ensure for the attachment part can withstand the load from cart.

ABSTRAK

Projek Ijazah Sarjana Muda tahun akhir ini menggariskan latar belakang projek mengenai " Reka Bentuk dan Pengoptimuman Lampiran Mobiliti pada Janitor Cart di Kampus Teknologi, UTeM ". Cabaran ke atas mobiliti troli pembersihan di mana kelemahan pengangkutan untuk naik ke tingkat dua dalam bangunan iaitu dengan menggunakan tangga. Projek ini dilakukan dengan melaksanakan kaedah yang sesuai. Menggunakan analysis Kaedah Pugh dalam memilih reka bentuk. Ia memastikan bahawa konsep yang dipilih adalah selaras dengan keperluan projek ini. Analisa kaedah House of Quality (HOQ) juga digunakan daripada analisis kriteria didapati reka bentuk memenuhi kehendak pengguna yang dalam reka bentuk tersebut. Analisis Elemen Terhingga adalah untuk menentukan simulasi dalam menganalisis reka bentuk untuk mendapatkan Tegasan dan Anjakan Von Mises pada reka bentuk. Dalam projek ini, reka bentuk lampiran telah dijalankan menggunakan perisian Reka Bentuk Bantuan Komputer (CAD) di mana untuk mendapatkan visual ilustrasi yang tepat untuk lampiran pada troli. Reka bentuk lampiran telah dibangunkan untuk kegunaan keselesaan. Proses pengoptimuman menggunakan Kaedah Pengoptimuman Topologi yang digunakan untuk meminimumkan jisim dengan mengekalkan kekuatan optimum reka bentuk. Faktor keselamatan reka bentuk ditentukan oleh analisis yang memastikan bahagian lampiran boleh menahan beban dari troli.

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LIST OF SYMBOLS AND ABBREVIATIONS

CAD	-	Computer-Aided Design
FEA	-	Finite Element Analysis
PM	-	Pugh Method
HOQ	-	House Of Quality
TO	-	Topology Optimization
PMMA	-	Poly(methyl methacrylate)
QFD	-	Quality Function Deployement
DR	-	Design Requirement
CR	-	Customer Requirement
DA	-	Differential Assesment
FE	-	Finite Element
kg	-	kilogram
cm	-	centimeter
2D	-	2-Dimension
3D	-	3-Dimension
mm	-	Milimeter
N	-	Newton
Mpa	-	Mega Pascal
K	-	Kelvin

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CHAPTER 1

INTRODUCTION

1.1 Background

Janitor cart also known as a transportation of cleaning equipment that carried for a cleaning purpose. A janitor is a transportation load that use for cleaning inside the building such as factory, school and other facilities like hotel, gymnasium and mall. Which each of the production of the janitor cart have it owns features and accessories to improve and maintain the cleaning process inside building. Janitor cart is important for cleaners to operate their cleaning services. It can carry load heavy items of the cleaning necessaries equipment by using the carts. The movement of the janitor cart also comes with different type of tires which easily adapt by specific surfaces. The setup production of the cleaning transportation equipment considers the mobility of the equipment in order to reduce fatigue and minimizing possibilities of injury that may experience by the cleaning staffs. The uses of the cart are also to achieve optimum cleaning services.

Structural design of the product mainly focused on the organization which important to keep all the items organized. The slots, shelves, hooks and garbage containers allow the cleaning staffs to split up works and organize the equipment efficiently. It is also important that the security features are considered when designing the janitor cart. This is because the janitor cart is left open to the public when the cleaner doing their work.

Moreover, nowadays usage of janitor cart for cleaning services in Technology Campus UTeM, the choice of the product is relevant for building environment. It made up from combination of plastic and steel which makes the weight is reasonable. Hence, the products are useful for the cleaning staffs to do the cleaning services. However, there is some restrictions of the facility in the building setting that crucial for the staffs to finish their job. The building does not come with facility such as lift and elevator thus if affect the mobility of the janitor cart to move up to second floor. Furthermore, the total weight of the janitor cart and all the equipment also affect the mobility for cleaning staffs to bring the cart up to second floor. Developed the design of the attachments and optimize the design without neglect the safety factor and towards the cleaning staffs.

Figure 1.1 Janitor cart in Campus Technology UTeM

1.2 Problem Statement

Nowadays, cleaning services is one of the important parts in building services. Usage of janitor cart in cleaning services as cleaning kit transportation is a must be in it. Plus, this occupation usually filled with older age cleaning staffs. The movement of the janitor cart that done by the staffs leads to the mobility problems. The dynamic equilibrium of the human body is affected when turning during walking to exchange new direction of travel [1]. Cleaning staffs experienced frequently with this movement as their daily job which may leads to repetitive movements. Handling a pushing task with a high inertia and unpredictable mechanical motion affects muscle activity and movement problems. In cart pushing, immediate turns to avoid collision which need to be done in short time affect to muscle activation and body posture [1].

Cleaning services do a lot of movement posture from body movement which can be considered as repetitive movement in daily life. Standing posture where required efforts which employs of little muscle activity and subsequently applies on modest stresses towards spinal structures [1]. In the building environment that does not have lift or travelator, these indirectly add the lifting works of the loads up to upper floor. Lifting loads by using stairs need to be done carefully to avoid unwanted incident towards body. The posterior lifting techniques towards body part are an excellent procedure that are typically used to teach good lifting techniques. These techniques will minimize the likelihood of low back pain and it stress knee bending [1].

Most of nowadays janitor that exist in the market or that have been used for cleaning services have its own mobility preferences. However, this janitor carts have limits of mobility where not every building in education sector occupied with modern facilities such as lift or elevator. Which means janitor cart that use in this workspace environment are not portable enough to covered all the place in the building. Due to lack of features that might be able to bring the janitor cart to upper level by only using stairs, it might affect the task that need to be done by the cleaning staffs.

The implementation of Pugh Method for identifying the mobility attachments existing in market nowadays use for evaluating the features that occupied on each janitor cart. From the design that have been evaluated, optimization method will be used for adding some design which gives optimum features in janitor carts that used in Universiti Teknikal

Malaysia Melaka, UTeM Fakulti Teknologi Kejuruteraan, FTK. From the optimization of design which adding some mobility features, Finite Element Analysis will be done by using Catia V5 CAD software for initiate design of the attachment and using Ansys Inspire software to obtain the optimum design optimization of the attachment on the janitor cart.

1.3 Research Objective

Objective of this project is to achieves some of optimization in design of the janitor cart in Faculty Technology Engineering UTeM. Based on the problem statement according to the title of this project, these are the objective that must be achieve at the end of the project:

a) To conduct survey on mobility attachment used on cart.

b) To design a mobility attachment on janitor cart in Technology Campus, UTeM.

c) To optimize the design of a mobility attachment of the janitor cart.

1.4 Scope of Research

The scope of this research are as follows:

- Survey of the existing janitor cart design for the needs of UTeM cleaner staffs.
- Designing the selected attachment of the janitor cart using CATIA V5 software.
- Optimize the selected design by using Topology optimization.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is analyzing case studies which have been done by other researchers and formulating the relevance benchwork to our project topic. Since this study are related to the design and optimization of the attachment on the janitor cart, thus the studies will be focused on the existing types of janitor carts available in marketplace, types of CAD software that use for designing the attachment and type of the optimization method that most suitable for optimizing the design.

2.2 Janitor Cart In The Marketplace

Janitor carts has been used in many areas for cleaning services. Due to the complexity for handling all the cleaning equipment for cleaner staffs to bring along during cleaning purposes, the ideas of production a janitor cart can ease the process. In order to gives the cleaning staffs the mobility that they need to bring and use the equipment for sweeping, mopping, collecting rubbish, storing their belongings wherever they need when they performing their jobs, there were introduced of janitor carts [2]. The designed used on the janitor are important for the used of it during cleaning services in every building environment setup.

2.2.1 Hotel Janitor Cart

In hotel management system, the cleaning services for hotel to ensure the optimum comfortable level and cleanliness of the room for guest's experience. The design of janitor cart for hotel cleaning services is focused on the size, level of the compartment and the number of shelves needed. The ideal of the janitor cart for hotel is must be capacious spaces implemented on the cart that be able to carries supplies which needed by the cleaning staffs. Plus, the cart should be easily movable as it contains large amounts of supplies and lastly suitable tire for ease the movement process. The ideal and suitable of the design on hotel's janitor cart can easily help the cleaning workers to maintain cleanliness level areas of hotels [3].

Figure 2.1 Hotel janitor cart

The Table 2.1 below shows the specification of the hotel janitor cart. The specifications of the cart show the important requirements for cleaning staffs to undergo the cleaning services in hotel building environment. The features of the design also help to increase the comfortless and easily to handle.

Table 2.1 Hotel janitor cart specification

Specifications	**Details**
Size	$1485mm \times 555mm \times 330mm$
Material	Fiber
Loading capacities	$100 - 150\ kg$
Number of bucket	2
Number of shelves	3
Number of wheels	4

2.2.2 Workplace Janitor Cart

Workplaces are usually known for working area such as office, school and library. The design of the janitor cart for workplace is focused on the size and capacity available to store and bring the equipment for cleaning process. Minimal and compact sizing of the cart enhance the capabilities function to adapt the environment of the workplace [4]. The mobility of the cart also important for easily to move on different type of surfaces such as on tiles or carpet. The durability of the product with combination of different materials ensures the cart to carry all the equipment needed for cleaning purposes.

Figure 2.2 Workplace janitor cart

The Table 2.2 below shows the specification of the workplace janitor cart. The specifications of the cart show the important requirements for cleaning staffs to undergo the cleaning services in the workplace building environment. The features of the design also help to enhance the comfortability concerns towards cleaning staffs.

Table 2.2 Workplace janitor cart specification

Specifications	**Details**
Size	$960mm \times 495mm \times 1160mm$
Weight	13kg
Load Capacities	125kg
Material	Polyethylene
Number of shelves	2
Number of wheels	4
Number of compartments	2

2.2.3 Hospital Janitor Cart

Hospital environment usually occupied by workers and patients which some of them might infected by disease, additional safety features which enable to minimize from spreading disease around hospital from affecting the workers or other patients. Infection control design which comes with material that can be easily sanitize such as non-porous and disinfected-resistant materials. Hospital cleaning services is categorized by light work which consists of cleaning bathroom and dusting while heavy work consists of vacuuming and mopping [5]. Hence, to reduce the workload experienced on workers, it also comes with secure storage for storing hazardous cleaning chemicals from easily reached by children to ensure healthy working environment. Special waste management implement on this cart also to separate the equipment compartment with waste disposal which it can prevent unwanted smell and odor for comfortability working environment.

Figure 2.3 Hospital janitor cart

The Table 2.3 below shows the specification of the hospital janitor cart. The specifications of the cart show the important requirements for cleaning staffs to undergo the cleaning services in the hospital building environment. The features of the design also help to enhance the comfortability concerns towards cleaning staffs and ensure the occupants patient’s health.

Table 2.3 Hospital janitor cart specification

Specifications	Details
Size	$620mm \times 1000mm \times 1080mm$
Weight	25.1kg
Capacities	200kg
Numbers of wheels	6
Number of shelves	5

2.3 Stair Climber Attachment

Attachments designed for climbing stairs typically aim to enhance accessibility or mobility. It can be useful for individuals with limited mobility to navigate stairs or assisting in carrying heavy objects upstairs more easily. These attachments often come in the form of portable ramps or stair-climbing devices for wheelchairs or walkers. They serve the function of making staircases more manageable and safer for individuals who may have difficulty climbing stairs independently. Some attachments might also provide support, stability, or assistance in navigating steps or uneven surfaces.

2.3.1 Light Weight Staircase Climber Trolley

Trolleys helps to reduce the stresses a human being experiences while lifting loads from one place to another over flat surfaces. However, when stairs are considered, normal hand trolleys fail. Carrying heavy loads between each floor using stairs need extra effort by using a conventional trolley. The idea concept developed by the Tri-Wheel made of Poly Methyl Methacrylate or PMMA in short, have a compressive yield strength around 120 N/mm^2 which lighter in weight compared to steel [6]. It is basically a three-spoked wheel, with individual wheels attached at each end. While moving along a flat surface, two of the three wheels will be in contact with the ground surface and will roll along the ground.

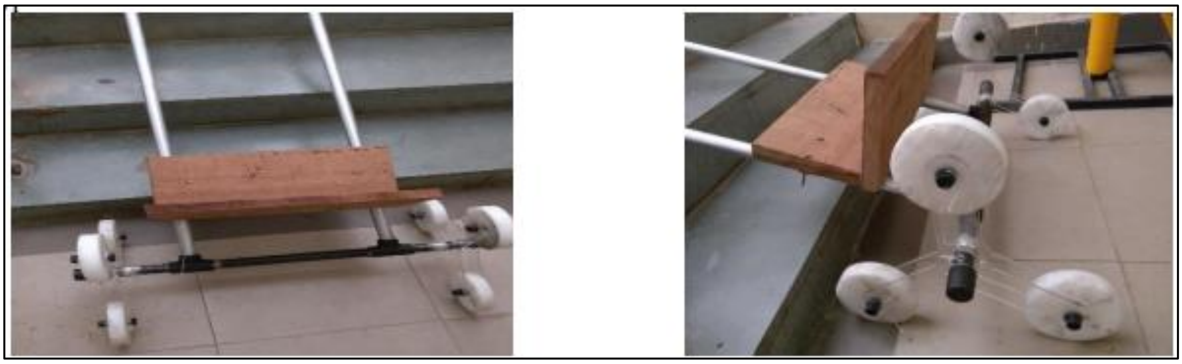


Figure 2.4 Tri-Wheel attachment concept on trolley (Ajay et al., 2017)

2.3.2 Belt System Stair Climber Trolley

Study of improving load transportation mobility on stair-climbing enhancements based on the Tri-Wheel attachment part concept. Using motor and belting system in idea concept helps in minimize the process of lifting up and down the load with fewer efforts and reduces injury incidents on human body [7]. The improvements of the mechanism achieve in weight reduction and ensure safety perspective of the mobility process.

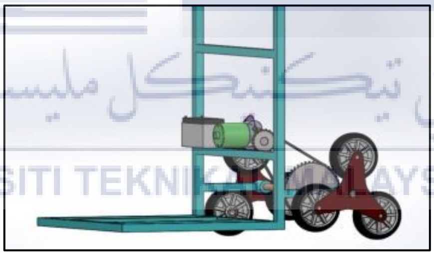


Figure 2.5 Motor and belts attachment system(Bahiram, 2020)

2.3.3 Active Mechanism Stair Climbing For Mobility Wheelchair

People with lower limbs disabilities suffers from movement limits which usually used a wheelchair that supports their movement from one place to another. Existing wheelchairs with lever propulsion control possess high planar locomotion capabilities. Critical obstacles such as stairs restrict their self-movements in daily life. The specialized wheels stated that where three wheels are attached to a frame 120° apart for step-climbing and wheels with linkage mechanism helps users can climb stairs independently. They propose a 4 bar linkage mechanism combined with motors and springs enhance the mobility of the wheelchair to overcome those obstacles [8].

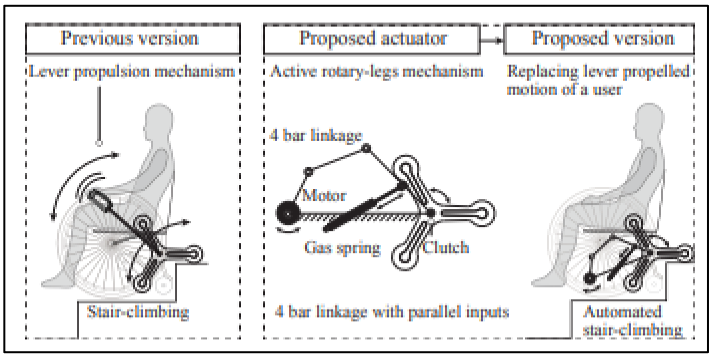


Figure 2.6 Active mechanism concept (Sasaki & Suzuki, 2018)

2.4 CAD Design Software

Computer-Aided Design (CAD) software usually is frequently used in order to design a new product especially in engineers, architects and construction managers. CAD programs consists of compact interface of design documentation such as geometrics, dimension and list of material which important for designing a new product [9]. Replacement of drafting and designing product from manual drafting to CAD design software give benefits to their users experienced. CAD software helps the users to create a design either to visualize the products in 2D or 3D dimensions which helps in construction and enables to proceed with other process which are optimization and modification design process. In order to design an attachment for this project topics, several studies and researches on several types of CAD software will be focused on Catia, AutoCAD and SolidWorks.

2.4.1 Catia V5 CAD Software

3D CAD design for engineering is important to develop a product to obtain high quality design. Catia V5 is one of the CAD design software which widely used to design and simulated the product with analyze the quality of the design. It also widely used in automotive engineering because of three-dimensional designing tools features exists in this software [10]. It also comes with features where while defining the products, users allow to combine electrical products, structural design information and system. By using Catia CAD software, the users can obtain their privilege to improve skills in designing a product.

Figure 2.7 Catia CAD software

2.4.2 AutoCAD Auto Desk software

AutoCAD designing software which also known as the industry standard in computer-aided design software. For professional engineering design which has been used in many industries. Autodesk was released in 1982 and it widely used in an engineers, architectural, construction designers [11]. It comes with better designing in 2D and 3D product which make it is more efficient. It also comes with featuring tools and features which enable to ease designing process for professional use which make it a versatile design software. AutoCAD can perform well for drafting process, which can deliver optimum design before undergo production process. As for analyzing the graphical requirements, engineers preferred to use this software because of easiest design process which existed in this software's tools [12]. The analysis features help the designer to frequently simulate the product for optimum result and improve the level of the quality of the design.

Figure 2.8 AutoCAD Autodesk software

2.4.3 SolidWorks CAD Software

SolidWorks is focused on the features which consists of parametric variables or mathematical equations in designing product. SolidWorks Computer-Aided Design software is one of the powerful software that has been used by engineers in designing process. Importance of SolidWorks CAD software is it gives benefits for combining several parts into assembly part which gives additional features other than others CAD software. Indirectly, it allows for engineer or designer to turns their ideas towards upcoming product in reality. It consists of designing product in 2D and 3D with efficient and reliability analytical tools which can be test the design before undergo development manufacture process. By having features that can analyzed and evaluated the uses and the life time of a material indirectly makes SolidWorks CAD software is sustainable towards engineering designers [13]. The interface of the software also easy friendly which makes it easy to learn and use the software.

Figure 2.9 SolidWorks CAD software

2.5 Pugh Method Concept Selection

The Pugh approach compares multiple design ideas against a set of criteria. It is a qualitative comparing tool. It was created in the 1970s by Stuart Pugh and is a widely used technique in engineering design. The Pugh technique is a quick and useful tool for evaluating design ideas. It is a qualitative strategy that does not depend on numerical data. This makes it an excellent option for initial design [14].

The evaluation concepts that commonly used in Pugh Method is by matrix selection. However, there are two disadvantages from the method selection which are because of the failure to continually achieve an optimal overall score, some potentially ideal concepts may seem unattractive and in a typical construction, the decision-maker needs to identify numerically useless weights and ratings. The concept of the evaluation of the method is by using a table comparison for matrix purposes [15]. Which the evaluation will determine the comparison of the several concept products along with the "datum concept" by determined the better criteria, worse criteria or same contexts.

CRITERIA	A	B	C
Size and appearance	+		-
Manufacturing and assembly	-	D	+
Installation and use	S	A	+
Service	+	T	-
$\sum +$	2	U	2
$\sum -$	1	M	2
$\sum$ S	1		0

Figure 2.10 Pugh Method Evaluation Concepts [15]

2.5.1 Quality Function Deployment (QFD)

Yoji Akao of Japan Academy of Science as the Quality Function Deployment (QFD) proposed that it should meets the quality characteristics and design quality standard of product must be determined from the customer needs. Design quality analyze in systematically from all features between elements of manufacturing process and services based on each function in matrix diagram. The features transform clearly to a variety of information to ensure that it can finally produce a product align with market needs. QFD converts user requirements into the relevant technical requirements of design, avoiding the decoupling phenomenon in the development process of new products [16].

2.5.2 House of Quality (HOQ)

House of quality is one of a design analysis tool which enables the engineers to conduct and illustrate the objectives marketing and technical criteria requirements. In order to obtain the preferences from customer needs which it need to fulfill the marketing requirements. The selected criteria in analyzing a design product which by using HOQ should be identical due to the purpose of the product. The outlined of the demands was usually used by engineer designers in order to achieve the utility and its purposes of the system. The control measure which applied on the HOQ is where relevant engineering features which needs to improve technically where it helps engineers by implementing the system to ensure customers appeal [17].

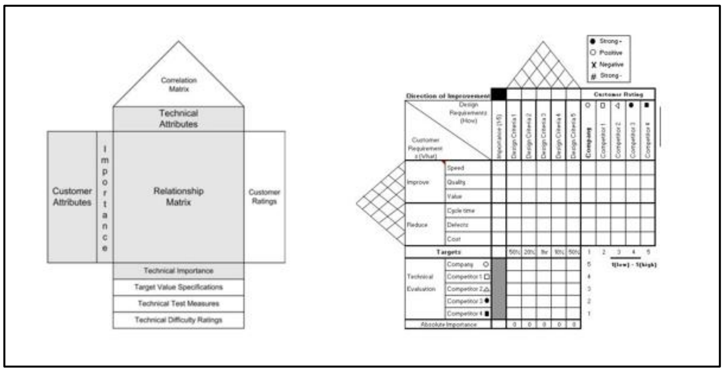


Figure 2.11 House of quality configurations [18]

2.5.3 Customer Requirement and Design Requirement Relationship

An important factor in design selection is the relationship between design requirement(DR) and customer requirement(CR) it helps identify which DR should be prioritized in order to meet CR and ultimately increase customer satisfaction. Matrix analysis and relationship ratings are employed in the context of Quality Function Deployment (QFD) and the House of Quality (HOQ) to examine the relationship between those two entities [19]. Furthermore, correlations between CR and DR must be taken into account throughout the design selection process since they account for various elements including available resources and cost trade-offs, which can result in both possible cost savings and enhanced overall quality of the product or service.

2.5.4 Enhancement Customer Requirement and Technical Requirement Matrix

Customer requirements may be categorized as either objectives or constraints both of which have unique contributions to concept feasibility and quality. The objective of CR is must be optimize at maximum or minimum of continuous quality improvement within its limits which not affected the quality of the design [20]. Incorrect HOQ development leads to all CRs presented incorrectly and can be improve by the differential assessment (DA) method with specifying constraints in a traditional HOQ to be used as a comprehensive repository for the entire design specification.

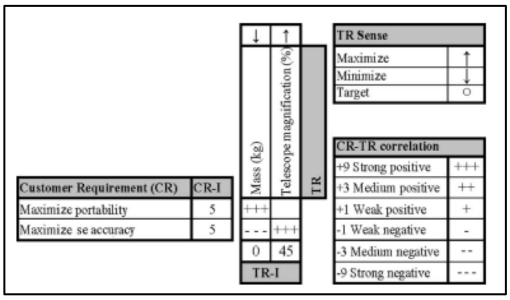


Figure 2.12 Specific relation between Customer and Technical requirement (Leary & Burvill, 2007)

2.6 Optimization Method

In recent years in engineering, designing a product for customers use give advantages in easier life and enhance productivity. Designing a product need to undergo optimization process which helps many features for engineer and company. Optimization methods usually to find variable values that optimize a multivariate objective function under a set of constraints. Optimization techniques are frequently used to create solution for minimizing costs, maximizing profits and reduces amount of raw material on a product [21]. Among optimization methods, linear programming is widely used because of its ease for implementation and because of its greater stability and convergence in comparison with other methods [22]. The method that uses in engineering for designing and manufacture the product for optimization method is Topology optimization, Topography optimization and Lattice optimization.

2.6.1 Topology Optimization

Structural optimization is one of the most important fields in the foundation of optimization. In order to achieve a lightweight product, topology optimization is one of the computational calculation methods which precise in developing advanced material. By improving quality and reliability in well-mannered with maintaining low cost is some parameters that need to be measured. The method required different strategies which has been use with highly problem dependent. Topology optimization is one of an optimal optimization method to defined optimization problem by an engineering designer. It also known as preprocessing tools for sizing and shape optimization because the usual sizing and shape optimization cannot be changed by the topology structure during solution process.

There are two types of topology optimization which consists of discrete and continuous and it is depends on the type of the structure. The optimum layout design and topology problem which is existing in determined the optimum number of the structural members is important in discrete structures. In other types of the of the topology optimization which is continuum structures, the shape of internal boundaries and external, along with the number of inner holes will be optimized simultaneously to a predefined design objective [23]. As mention the parameters, it will be specified within a given 2D or 3D design domain with given boundary region.

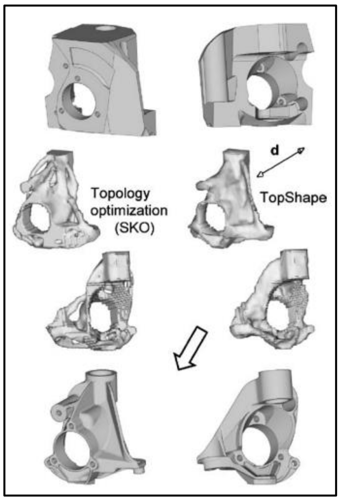


Figure 2.13 Structure Design of Topology Optimization [24]

2.6.2 Shaping and Sizing Process

Typically, topology optimization structure has a complicated geometric configuration. By applying some additional adjustments which function to improve the manufacturability of the product, it enhances the process by reducing the possibilities in conventional manufacturing process. As a product that have been designed in CAD software, the model has been applied with Finite Element Method which creates boundary domain on the part to achieve a smooth optimizing process. Topology optimization results will show the necessary shape on the part and it will undergo analysis process to determine the structural performance of the model. The functions and criteria should meet customer need in order to have an optimum final result. Figure 2.10 below shows the flow of shaping and sizing process for Topology optimization.

Figure 2.14 Shape and sizing process in Topology optimization [25]

2.6.3 Topography Optimization

Topography optimization method is an advanced form of the shape of the optimization. The method of the optimization is when a design region has been selected, then the selected shape region undergoes variable-based reinforcement process. Topography optimization is different than topology optimization where topography optimization utilizes shape variable instead of density variables which applying beads on the surface of the part [26].

Noise and vibration are one of the most problems issued which has been solved by adapting vibration control and passive sound. Applications of damping materials which have been widely use in industrial application. Damping layer on steel by using topography optimization can reduce vibration and enhance the strength properties [27]. The reduction in vibration results obtained from the thickness of the damping materials by determining the response surface method. Topography optimization provides a stiffer structure while giving a low mass increase, which keeps a constant thickness throughout the structure [28]. In topography optimization, a perturbation vector is applied to each node which in the design domain along the normal direction. This result of the method in a bead pattern in the optimized structure. Topography optimization performs well in reducing significant sound power compared to the initial design in automotive sector [29]. In order to minimize the manufacturing cost and improve the noise insulation performance, regarding to the enclosure panel design has been decided to used topography optimization as an ideal optimization method.

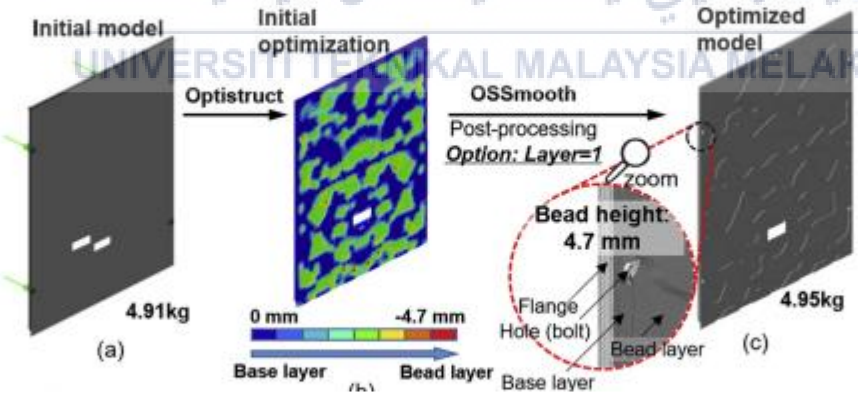


Figure 2.15 Simulation for Topography Optimization [27]

2.6.4 Lattices Structure Optimization

Lattice optimization of lattice structure was widely used in engineering sectors such as mechanical engineering, biological engineering and aerospace. The method of the lattice optimization structure is widely user because of the advantage of the production properties of the material. One of these geometries that has received increasing attention recently is the lattice structure because of its superior mechanical characteristics, such as its high strength-to-weight ratio [30]. The optimization on lattice structure also be enables heat dissipation and absorption of impact shock energy [31].

Lattice optimization of lattice structure classified according to several types of cellular materials which indirectly connected to the production of the optimization process based on the building unit cells. Foam, honeycomb, sponges, folded materials, and lattice structures are a few common illustrations of cellular materials. Non-stochastic orientations and open pores are characteristics of lattice structures [32]. Foam cellular structure was like cancellous bone and wood which indicated variables of foams structure. Unit cells inside the honeycomb structure are likely uniform in size and shape which comes in triangular prism, square prism and hexagonal prism. The type of architecture known as lattice structures is made up of a collection of spatial unit cells with edges and faces where it can be in uniform or non-uniform shape and size.

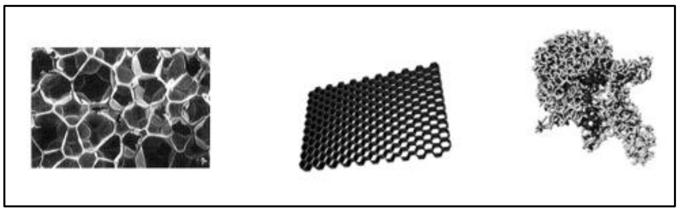


Figure 2.16 Foam structure, Honeycomb structure and Lattices structure [32]

2.7 Finite Element Analysis

Finite element analysis is the use of calculations, models and simulations to predict and understand how an object might behave under various physical conditions which solves numerical techniques and digital computational [33]. Engineers use FEA to find vulnerabilities in their design prototypes. Finite element analysis emerged as a way for computers to solve both linear and nonlinear partial differential equations. Which means that finite element analysis only gives an approximate solution which in numerical approach. FEA can reduce the number of physical prototypes created and experiments performed while also optimizing all components during the design phase.

By controlling the choice of finite element type and mesh such as their geometry, cross section, loading, boundary condition is the parameters that need to be considered. The behavior of different element which to be analyzed to access their suitability for stimulating structural member [34]. There are some different linear and non-linear region in stress-strain curves of the metal structure according to its geometrics structures. Three parameters that need to be considered on metal structure cross section which are compact, non-compact and slender in finite element analysis [34]. Compact cross section consists of thick plate thickness which can develop plastic moment resistance without undergo buckling effect. Non-compact cross section which part that the stress in extreme fibers reachable of the yield stress. Lastly, slender cross sections are those buckling effect will occur in one or more section of the cross-sectional part before reaching the yield strength. Finite elements models used to perform different analyses and parameter studies on different cross section according to their types of cross section.

2.7.1 Fundamentals in Finite Element Analysis

Classify of the shell element categories usually used in modelling structures which one of the processes of FEA. Implementing patch of the CAD geometrical model with creating mesh process enables to created domain on the model surface with shell elements that connected by nodes. Applying loads on the nodes is necessary to prevent the model boundary from moving. The main shells element available in FEA are plane stress elements (2D) and 3D elements [35]. Increasing the number of nodes affects the introduction of the irregular elements. While conducting the finite elements tools, the methods of process must be followed by the preparation phase, formulating finite elements problem and post processing. Figure 2.13 below shows the illustration of meshing on models by using finite element method with different types of shell elements

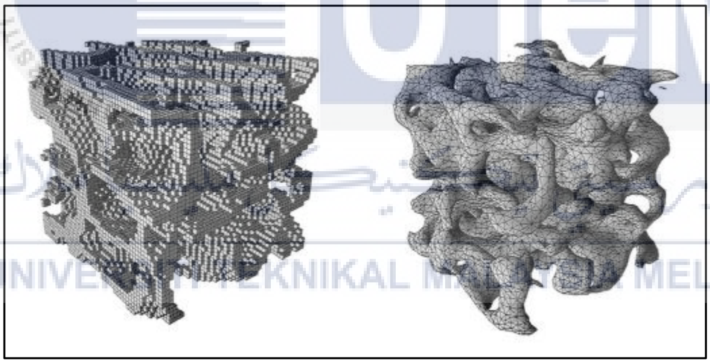


Figure 2.17 FE models simulated with hexahedron meshing (left) or tetrahedron meshing (right) [36]

2.8 Structural Static Analysis

This type of FEA analyzes a scaled model based on proportions. The test maintains that any structure that is sound on a small scale will be able to handle the same interactions with the full-scale structure and produce the same results. The structural static analysis use to determine the structural load applied to investigated the effect of structural impact on a part. In order to calculate the factor of safety for the prototypes, Von misses stress will be considered to get the idea along with the stress on the object [37]. To be specified of the structural static analysis, the relevant dynamics and aerodynamics parameter should be ignored. A rigorous finite element analysis is incorporated to evaluate the developed Von Mises Stress, total deformation and subsequent equivalent strain emerges at different parts of the proposed prototypes when the weight was applied. Von Mises Stress is used to predict the stress distribution over different parts of the prototypes.

2.9 Summary

The conclusion for this chapter shows the researches finding that has been studied from the previous researches which related to this project. The existing technical specification from existing janitor cart in marketplace shows the relevant requirement which suitable for building environment for each sector. The function of features which consists on the janitor cart is to make the cleaning process easy for cleaning staffs by doing their cleaning task. In order to design an attachment for mobility of the janitor cart for lifting to second floor by using stairs, the studies of the proper methods have been done to generate optimum method related to this project. Implementing the Pugh Method for determining the selection conceptual design of the part based on the listed criteria fulfill the customer needs. Designing process of the part has been determined by studying previous researches on listed CAD software. Catia v5 CAD software shows the significant advantages for designing the attachment part with existing additional features that helps in designing process. Optimization process by using Topology Optimization method shows the simulation on the optimized design comes with results on Von Mises Stress and Displacement which enable to analyze the safety factor of the design. It is ensured to maintain safety precaution for customer uses.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is clearly defined all the method that use to conduct the project. This is because in order to ensure objective of this project is successfully obtained. In order to begin with, firstly this methodology starts with creating a flow chart to ensure the project process flow is understandable and systematic. The first process of this project is determining the base design of the attachment be able to improve the mobility of the janitor cart. The base design will be conduct by CAD software by using Catia V5. The attachment design will be transferred to another software for optimization process. From there, optimization process will be conducted by using Ansys Inspire software and using TO method. Linear static evaluation will be conduct to determine the tests parameters that need to observe of the product that will produce for attachment on the janitor cart. The tests that will be evaluated in linear static test are the stress and the deformation of the material.

The second process started after achieving the linear static result on the base design, then the optimization process where new design will be obtained after eliminating unwanted material on the design. By adjusting to the best desirable design of the attachment of the product, the design will undergo linear static test again. This test is also to determine the stress and the stiffness of the optimized design. After the optimized design passed the linear static test, the process will move for the final design.

The last process of the optimization process is for the final design. The final design of the attachment on the janitor cart is where the design is finalized with better appearance illustration on how the product will be undergo production process. This final process also needed to be evaluated with linear static test to ensure the stress and the stiffness of the design passed for production purposes.

3.2 Flowchart

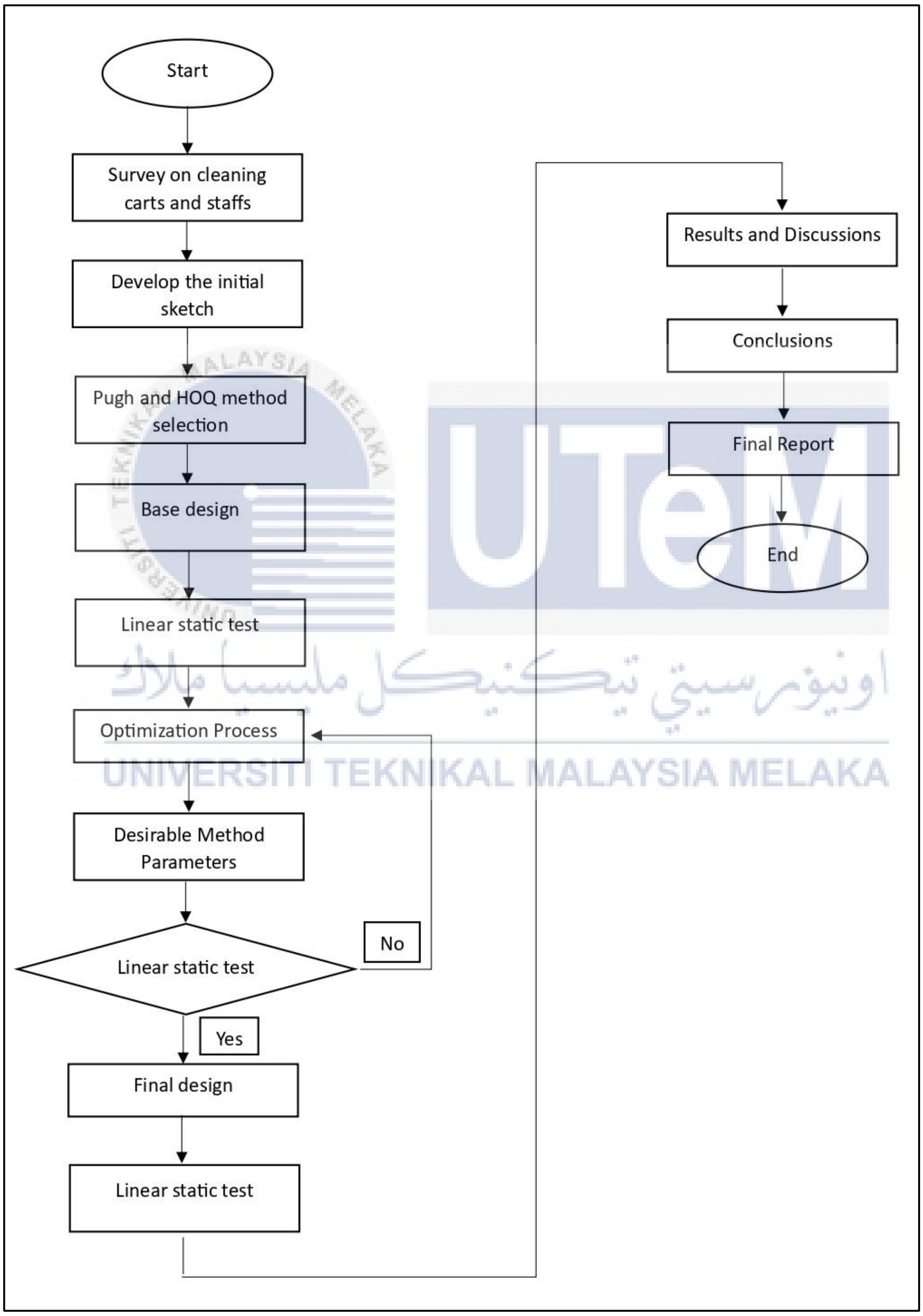


Figure 3.1 Flowchart of project

The flowchart on Figure 3.1 above is indicating the process flow which will be conduct the project from the beginning until the end of the process. The base design that will be conduct on the CAD software by using Catia V5, then the design will implement suitable material for the attachment of the janitor cart. From the selected suitable material, the material properties will be determined for the evaluation process purposes. Firstly, the linear static test for the stress and stiffness of the base design is to determine the benchmark of the design before undergo the optimization process.

Next, in order to obtain the desirable parameter of the test, the optimization process of analyzing the linear static test will be conduct by referring parameters setup and process according to the literature review with same observing method.

The linear static test which to evaluate and observe the stress and the stiffness of the material, based on the material properties of the material implement on the design will be test with higher possibilities value. This means to determine the withstand of loads for mobility of the janitor cart in the range of the stress and the stiffness of the attachment product. After the test of linear test has been conducted, the result and data will be recorded.

3.3 Flow of Project Planning (Gantt Chart)

The Gantt Chart table purpose indicated the task measure that has been planned since started the project plus it also indicated the actual period when all the task has been started and finishing the task. The flow of the project planning in Gantt Chart for PSM 1 is available in APPENDIX C. While the flow of project planning in Gantt Chart for PSM 2 is available in APPENDIX D.

3.4 Survey Form on FTK UTeM Janitor Cart

This survey which has been made to achieves a better understanding on existing janitor cart in FTK UTeM towards cleaning staff's thoughts and preferences while using it during cleaning tasks. This survey has been conducted by hardcopy which all the cleaning staffs has answered the survey by face-to-face method which easily for their understanding and answered it straightforward. The survey question can be referred on APPENDIX A.

The survey consists of several question which perception and thoughts on the existed janitor cart. All the participants have answered questions related to their gender, age, working hours and working experienced. Plus, they also have been asked about the janitor cart mobility during undergo cleaning purposes towards their health and perception for lifting up to second floor. All the participants have responded the survey about "Design and Optimization of attachment on janitor cart in FTK UTeM "positively. They were freely to offered their thoughts which greatly improved of this project and upcoming outcomes.

3.5 Survey Questions on Design Criteria of Attachment

The survey question on the design criteria of the attachment design is important to determine the design meets customer requirement. The constructed question on the survey will be evaluated using QFD method. The criteria listed are an important element which helps to improve the mobility movement on janitor cart to lift up on second floor. The results obtained from the survey questions will be align with the technical requirements on the attachment part to fulfill the customers need from the attachment part. The survey questions of design criteria of the part can be referred in APPENDIX B.

3.6 Technical Drawing of Janitor Cart

The technical drawing of the janitor cart function to helps the conceptual idea design of the attachment part in order to improve the mobility to climb stairs up to second floor. The dimension of the existing janitor cart has been taken in Campus Technology UTeM by using some proper equipment to be able identify an accurate value for each part. The maximum height and width are important for the concept design of the attachment part. The dimensions of the other parts on the janitor cart also have been taken carefully to minimize for an optimum result of the idea concept design. The technical drawing was constructed by using Catia V5 CAD software.

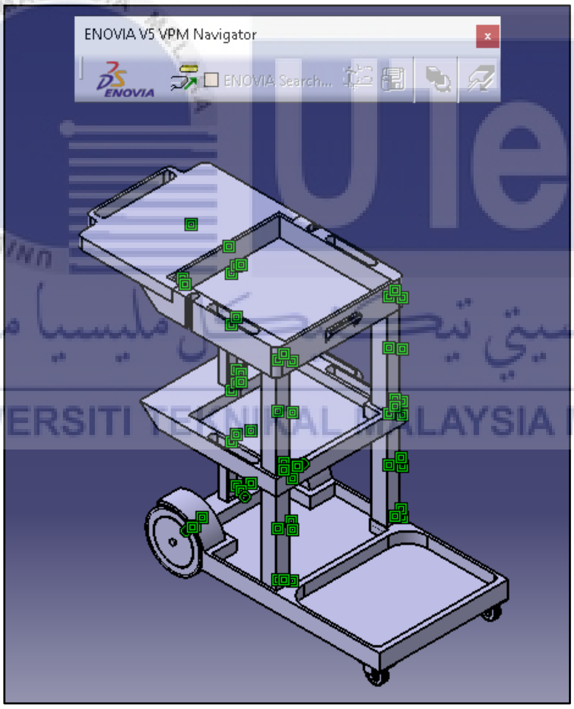


Figure 3.2 Technical drawing of janitor cart

3.6.1 Applying Material On Janitor Cart

The material of fabrication on janitor cart that existed in Campus Technology UTeM are made up from High Density Polyethylene (HDPE) which are usually known as corrosion resistance and low cost material. After finishing create the technical drawing of the cart, applying material on each part allows to obtain the actual mass of the cart before undergo the simulation process.

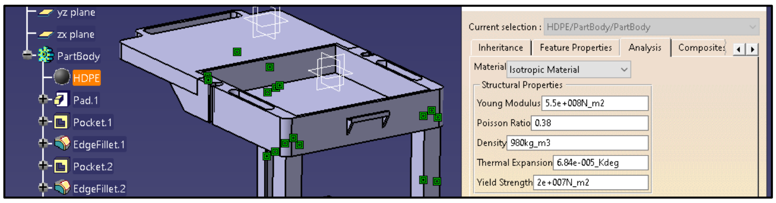


Figure 3.3 HDPE material mechanical properties

The material obtained from the material library has been edited to the actual mechanical properties for material used on the janitor cart. This is to ensure the mass obtained is based on the actual material used on the janitor cart. The material used for tire on the back of the cart is made up from Thermoplastic Rubber (TPR) which provides good impact resistance.

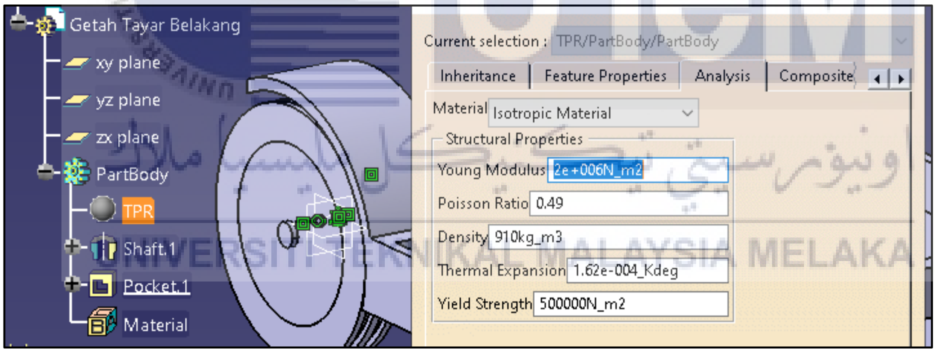


Figure 3.4 TPR rubber material mechanical properties

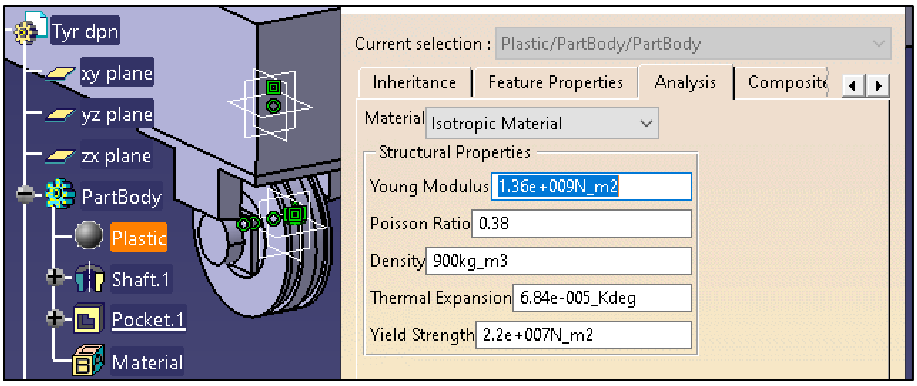


Figure 3.5 Plastic material mechanical properties

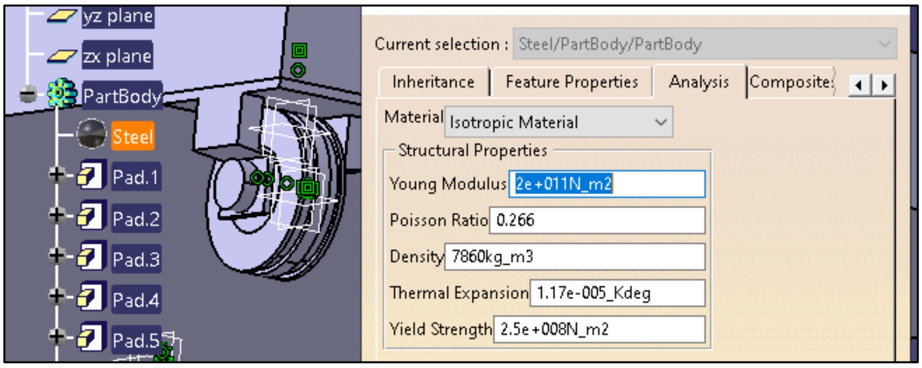


Figure 3.6 Steel material mechanical properties

3.6.2 Maximum Weight On Janitor Cart

Technical drawing of the janitor cart has been measured by using suitable tools which to obtained all the dimensions on each part. By using Catia V5R21, the design drawing has been done by all the dimensions taken. The applying material process on each part were important in order to achieve the total mass of the janitor cart. Based on the material that has been applied, the total mass of the cart is 35603.646g or 35.603kg. The mass of the cart is important for undergo the simulation test on the design of the attachment for climbing stairs on cleaning purpose.

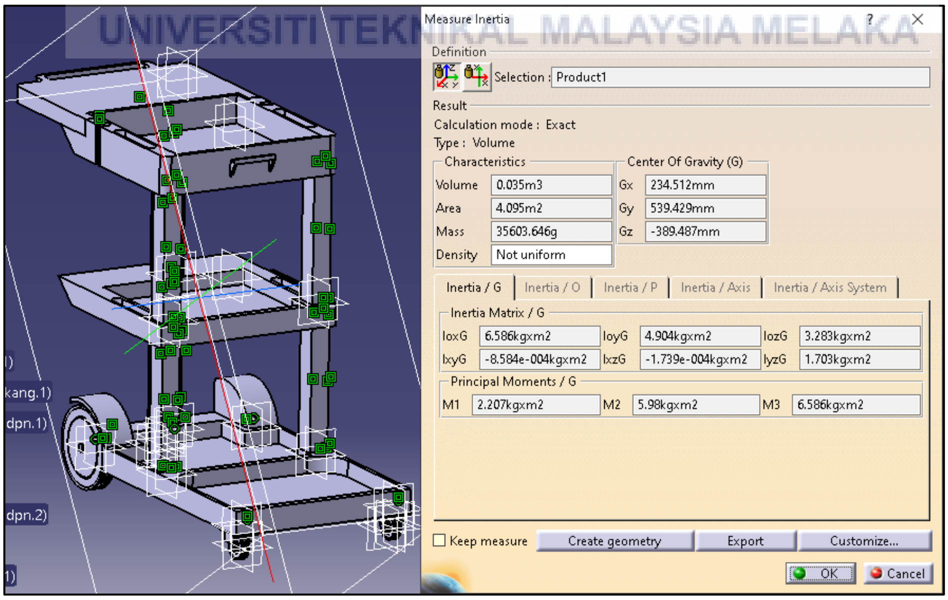


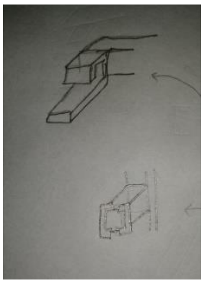
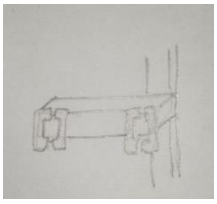
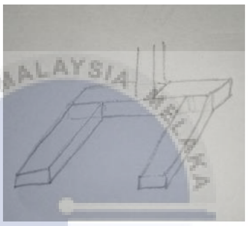
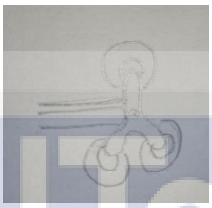
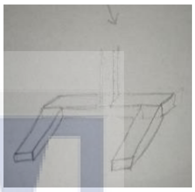
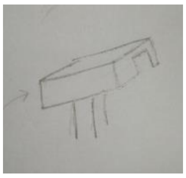
Figure 3.7 Weight of janitor cart

3.7 Morphological Chart

An approach for systematically and analytically developing concepts is the morphological chart. Potential components are displayed in a morphological chart based on their roles. The methods used to carry out the tasks are listed in rows, while the functions itself are provided in columns. This produces a matrix of elements and functions that serve this objective. A concept is produced by carefully choosing and mixing several elements.

The diagram of morphological chart is composed of functions which in columns and components which listed in rows. All the parameters listed are define the features for a product need. The parameters are important to the solution. Therefore, the components are the methods to achieve the specifications. These parameters are abstract and show a category.

Table 3.1 Differences between Design A, B and C

Initial Design	**Design A**	**Design B**	**Design C**
Handle holder			
Base support		 	
Stair rail attachment			

3.8 Initial Design of Janitor Cart Attachment

Initial design is an alternative method of design selection which emphasized by choosen from a large number of alternatives which must been evaluated. The presentation of an excellent solutions which clearly demonstrate how the condition of different design problems, including the practical demands related to the function of structure and meets safety external actions leads to an effective project.

As the mentioned of previous technical and appearance design consideration, it also leads to the designer personal preferences on obtaining the desirable design of the attachment on the janitor cart. However, the it should consider the development measure along with societal considerations which must be implemented to achieve the project objectives. There are three different design ideas have been sketched with various structure and its function to enhance the mobility of the janitor cart.

3.8.1 Design A

The Design A as shown in the Figure 3.8 below is the first ideas of the design idea in order to achieve the mobility of the janitor cart to go up to second floor. The dimension of the design is covered for the height of the janitor cart. It comes with features that base to support from the bottom of the cart. It also consists of two clamps that located on the top shelve and bottom second shelve. The design of the clamps on the top shelves also have support to minimize the load stress on the attachment.

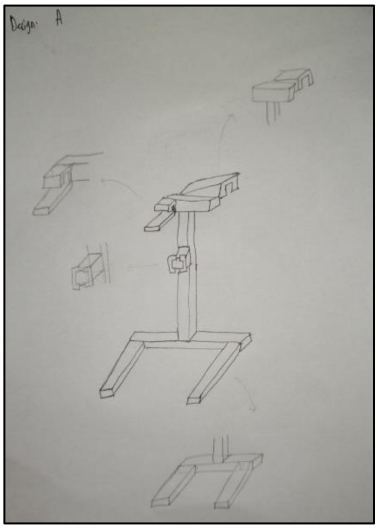


Figure 3.8 Design A

3.8.2 Design B

The design as shown in Figure 3.9 below shows the ideas design for Design B. It comes with different design compared to the Design A. This design is consisting of single base support covered in the middle of the base with double tri-tires on each side. It consists of one clamp located at under the top shelve.

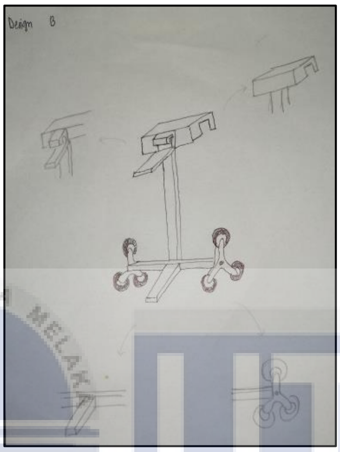


Figure 3.9 Design B

3.8.3 Design C

The design C as shown in Figure 3.10 below shows the ideas concept for Design C. This design is adjusted from Design A. The support has only a clamp at the second shelve of the janitor cart. It also comes with the base support on the janitor cart.

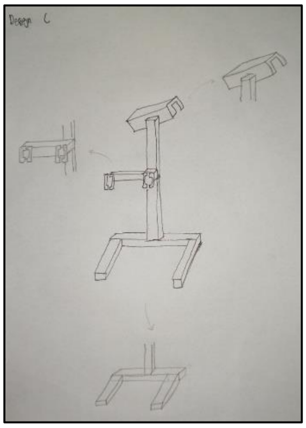


Figure 3.10 Design C

3.9 Selection of Concept Design

3.9.1 Pugh Method selection

Table 3.2 Pugh Method selection based on criteria selection

Criteria	A	B	C
Antirust component	+	+	+
Compact size	-	+	+
Lightweight	0	+	+
Durability	+	-	-
Minimum operation	+	-	-
Ease operation	+	0	0
Cost	0	+	0
Sum +	4	4	3
Sum 0	2	1	1
Sum -	1	2	2
Net score	3	2	1
Rank	1	2	3

The Pugh Concept Selection Method is a quantitative approach as an alternative of choices to determine the final rank for each design. This technique is widely used in engineering to make design decisions as also used to determine the product alternatives of various criteria. All the items for each criterion have been scored which encounter the advantages, disadvantages or consist of same elements compared to each design ideas. The total score from the evaluation process indicates the ranks for the ideal design for the attachment on the janitor cart

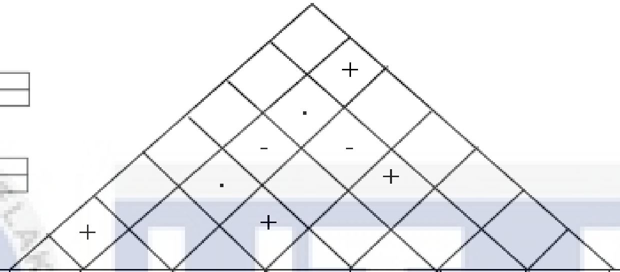
3.9.2 House of Quality (HOQ)

Correlation

+	-	.
Positive	Negative	No correlation

Relationship

9	3	1	
Strong	Moderate	Weak	None



Customer Importance Rating
1: Low – 5: High
Competitor Benchmark Rating
1: Low – 5: High

		Direction of improvement	↓	0	↑	↑	↓	0	↓	Competitor Benchmark		
Category	Importance	Technical Requirements / Customer Requirements	Cost of production	Dimension, mm (900*500*400)	Expected lifetime (3 years)	Strength, kg (35-40)	Minimizing time, s (30-40)	Material (Lightweight)	Weight, kg (2-3)	Competitor 1	Competitor 2	Competitor 3
Specification	3	An antirust component			3	3		3	9	4	3	4
Features	5	Easy to install	1		9		9		3	1	2	1
Features	5	Easy to dismantle	1		3		9		3	1	2	1
Features	5	Easy to carry on cart	1	9	1		3		3	5	3	1
Specification	3	Compact size		1		3	3		3	5	2	1
Specification	5	Lightweight	3	1		3		3	9	5	4	1
Specification	5	Can support cleaning load			9	9			3	5	5	5
Specification	4	Minimum operation movement			1		9			3	2	5
Features	4	Locking system	1				3			1	3	5
		Technical Importance Score	34	49	123	78	162	24	141	611	Total	
		Importance (%)	5.56	8.02	20.13	12.77	26.51	3.93	23.08	100	Total	
		Priorities Rank	6	5	3	4	1	7	2			

Figure 3.11 Result of HOQ

This study's results show that developing a high-quality house satisfied the customer's requirement for an engineering aspect. The information gathered was then used to develop the technological solution. According to the HOQ survey, ‘Minimizing time’ is the most important functional criterion. Follow with the second criteria is ‘Weigh’ which are suitable for cleaning staff to use the attachment. Next is ‘Expected lifetime’ which shows the durability of the attachment to lift the cart. Nevertheless, the criteria for ‘Strength’ also need to be considered for the design. Next, the ‘Dimension’ must be fulfilled for the suitable size of the attachment. In addition, the ‘Cost of production’ and ‘Material’ must be discussed in detail.

3.10 Base Design on Selected Ideas

This project is carried out by undergo base design process where the initial design of attachment of the janitor cart for improving its mobility to climb on second floor of the building. The base design of the project will be designed by using Catia V5 CAD software. From the previous researches on evaluating preferred CAD software for designing process, Catia V5 CAD software has been selected for designing the attachment process because of its simplicity of interface and friendly use for undergo base design process.

3.10.1 Create the design using Catia V5R21

The parameters and dimension of the attachment for the janitor as follow as an existed on the marketplace. The designing process of the product as follow of the command on the Catia V5 software which easily to interpret and use for completing the designing process.

The selected concept design ideas have been sketched in Catia V5 CAD software which has been followed the range of dimension which must be enable to enhance its mobility by using stairs. The body of the attachment consists of three wheels that attached on the part.

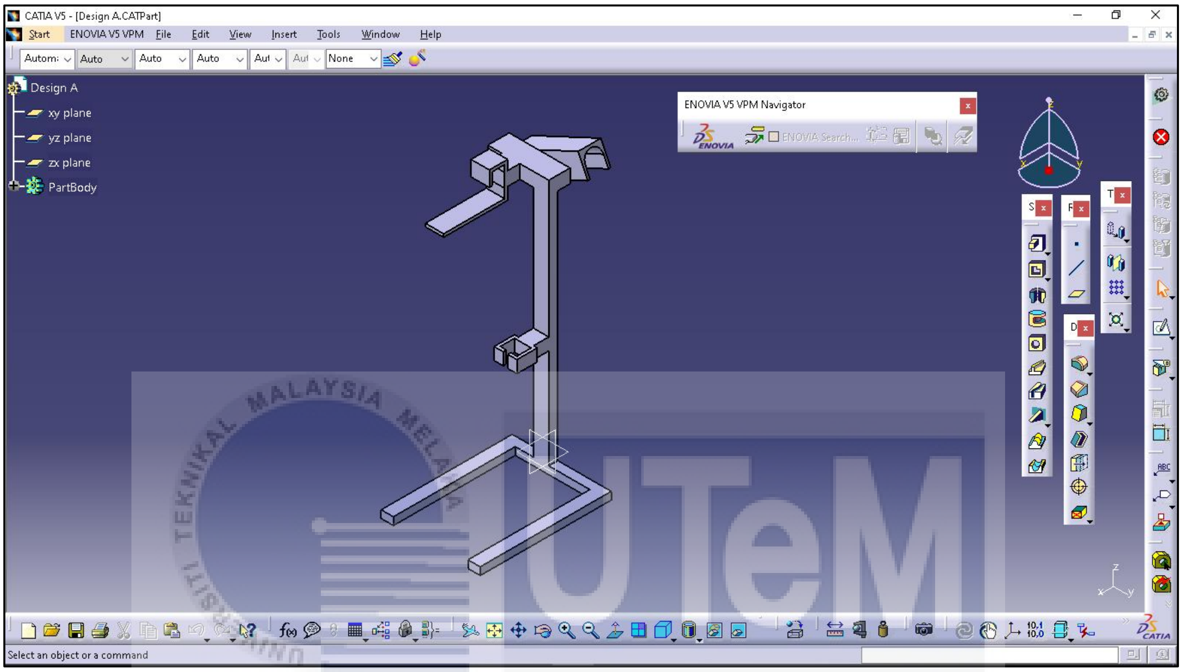


Figure 3.12 Design in Catia V5R21

3.11 Linear Static Test

Linear static test is a test that which been used to analyze the designed product from the CAD software. The previous exported of the file from the designed process, the file has been imported into the Altair Inspire 2022 software for undergo linear static test.

Altair Inspire 2022 software enable to perform some analyzing process such as linear static process. The linear static test on the base design is to determine an initial benchmark for the safety factor of the design. This is to ensure the optimized value safety factor has been improved in order to achieve the objective of the project. The features such as applying load and supports which applied on the part of the attachment gives initial simulation which real loads will apply on the product.

3.11.1 Selection Partition and Design Space

Design space and partition function to separate the base design of the attachment part to undergo the linear static test and optimization process. By using Ansys Inspire software features and tools, the of part attachment of the janitor cart has been imported into the software. The part has been applied the selection part for partition which located at loads and support will be placed. The design space of the part is determined for optimization process.

3.11.2 Set up Loads and Support

The setup of loads and support on the attachment of the janitor cart is determined by the mass that obtained from the drawing and applying material of the janitor cart. The total mass of the cart will be times with gravitational value because of lifting process. By using formula calculation of load as referred in APPENDIX E.

3.11.3 Set up Load Case

The purposes of conducting the load case setup on the base design of the attachment part is to differentiate the analyzing simulation based on different direction of load. The setup of the load determines by the location of the load happen on the surface of the attachment part. The results from the load setup will be simulated to observe on the selected surfaces load placement.

3.11.4 Material Application

In this analyzing and optimizing design software, it also comes with applying material features which can be applied from existing library from the toolbars. The materials of the attachment product have been selected according to its properties and applicable to undergo the mobility of the janitor cart. The existing material also has come with its properties which makes it easier to proceed analyzing process of the product. The material selection on the design part is to differentiate the results on part from analyzing process. (ABS) Plastic, High-Density Polyethylene (HDPE) Plastic and Aluminum (2024-T3) were selected to undergo analyzing process and determined the results obtained. However, the material selections are the important part where to identify the availability of appropriate materials to apply on the design.

Table 3.3 ABS Plastic material properties

Properties	**Value**	**Units**
Young Modulus, E	$2.0e^{3}$	MPa
Poisson's Ratio	0.35	
Density, $\boldsymbol{\rho}$	$1.06e^{-6}$	$\frac{kg}{mm^3}$
Yield Stress, $\boldsymbol{\sigma Y}$	$4.5e^{1}$	MPa
Coefficient of Thermal Expansion, $\boldsymbol{\alpha}$	$6.3e^{-5}$	/K
Thermal Conductivity, $\boldsymbol{\lambda}$	$1.6e^{-4}$	$\frac{W}{(mm \times K)}$

Table 3.4 HDPE Plastic material properties

Properties	Value	Units
Young Modulus, E	$1.2e^{3}$	MPa
Poisson's Ratio	0.46	
Density, $\boldsymbol{\rho}$	$9.5e^{-7}$	$\frac{kg}{mm^3}$
Yield Stress, $\boldsymbol{\sigma Y}$	$4e^{1}$	MPa
Coefficient of Thermal Expansion, $\boldsymbol{\alpha}$	$6.8e^{-5}$	/K
Thermal Conductivity, $\boldsymbol{\lambda}$	$2.2e^{-4}$	$\frac{W}{(mm \times K)}$

Table 3.5 Aluminum (2024-T3) material properties

Properties	Value	Units
Young Modulus, E	$7.5e^{4}$	MPa
Poisson's Ratio	0.33	
Density, $\boldsymbol{\rho}$	2.77×10^{-6}	$\frac{kg}{mm^3}$
Yield Stress, $\boldsymbol{\sigma Y}$	$2.758e^{2}$	MPa
Coefficient of Thermal Expansion, $\boldsymbol{\alpha}$	$2.28e^{-5}$	/K
Thermal Conductivity, $\boldsymbol{\lambda}$	$1.21e^{-1}$	$\frac{W}{(mm \times K)}$

3.11.5 Analysis Base Design

Analyzing process is a process where once all the parameters and properties of the attachment product has been applied on the product, the linear static test will test the product and analyze the simulation of the part from the designing process. This feature enables users to identify some parameters that fulfill of this project to achieve the objective stated by the end of the project. Results from the analysis process shows the Von Misses Stress and Displacement of the designed product. Von Misses Stress shows the maximum and minimum stress which occurred on the product after applying the loads and supports.

Additional feature comes with analyzing simulation indirectly enhance users for easily analyze the results which possible location of the maximum and minimum stress occurred on the product. The results of Displacement obtained from the analysis process shows that the possible elongation of the part after applying loads and supports. It shows the possible defect that happen from the base design process to evaluate either the base design can proceed for undergo optimization process or not. The Displacement occurred on the product also can be determine the maximum and minimum on the part from the simulation view.

3.12 Optimization Design

The optimization process of part design to reduce unnecessary part while maintaining the durability to stand the load applied. The observed simulation from static linear test has shown the design can undergo the optimization design process. Topology optimization has been selected in order to implement on the designed product. The optimization process is to identify the design product on which location on the part can be optimized by reducing material after applying the loads and supports. The optimization also maintaining the outcomes parameters of the part.

3.12.1 Shape Control Configuration

Before undergo optimization process, the part must be set with shape control configuration. The symmetry control of the part has been used with Symmetric Controls. It is function for optimized shape with symmetric pattern. The draw direction also applied on the part which function for ensuring the physical manufacturing process.

3.12.2 Setup for Topology Optimization Process

The setup for Topology Optimization process is by determined the objective of the process. The objective has been set to maximize stiffness with mass target 30%. The mass target is to specify the amount of material to keep on the design part. This mass target value acceptable for ensuring the durability of the attachment part to withstand the load.

3.13 Analyzing The Optimized Design

The obtained of optimized design after the Topology optimization process, the design also will be analyzed for linear static test. The results of maximum Displacement and Von mises stress also will be record for evaluation comparison. The simulation also shows the location and visualization the possible defect on the part once has been optimized.

3.14 Calculation Safety Factor

Safety factor of a product is a countermeasure for the assessment measure for a safety precaution on a product. It also helps the designer's engineer for determined either the product can undergo production process or not for user safety when using the product. The objective of safety factor calculation to ensure a safe design. As given the formula of safety factor in APPENDIX F, these are the results for each safety factor.

3.15 Final Design

Final design is a process after the optimization process have been undergo linear static process. The linear static process must be repeated which to ensure the properties and strength of the product is on range for mobility of the janitor cart to fulfill the work done. Once the simulation and data for the linear static test have passed, the final design will finalized the attachment part in Catia V5 CAD software.

3.16 Summary

The conclusion for this chapter presents that the proposed methodology to design and optimizing the attachment part for mobility on janitor cart to go on second floor using stair. The ideas and flows of this methodology indicate the progress for achieving the objectives for this project. Selected process from the previous researches helps in order to identify the suitable method in determine an optimum conceptual design and illustrate the designing sketch by using suitable CAD software. The optimization process by using the method functions to obtained optimized design and undergo analysis test for determine the deformation and stress occurred on the part. Predicted results obtained in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, it shows the final project finding where by illustrating the data analysis and their implications. The data obtained from the simulation which easily to determine the outcome results. By using Ansys Inspire 2022 software, it is important for undergo analysis process. Ansys Inspire 2022 software also an important simulation tools for designers and engineers to analyze the designed part. This is achieved by eliminating geometry preparation and unnecessary material on the part from structural simulation.

4.2 Survey Response

The survey form that has been made for collecting data on the staffs and gathering information based on the mobility of the existing janitor cart. The information gather from them indirectly helps the improvement for this project in order to achieving the objectives for enhance the mobility of the existing janitor cart to lift up on second floor. The criteria of selected question also help to improve the understanding on staffs while using the cart for cleaning purposes. The scale of the survey response indicates as in the Table 4.1 below:

Table 4.1 Scale of survey respones

Scale	Details
1	Strongly Disagree
2	Disagree
3	Neutral
4	Agree
5	Strongly Agree

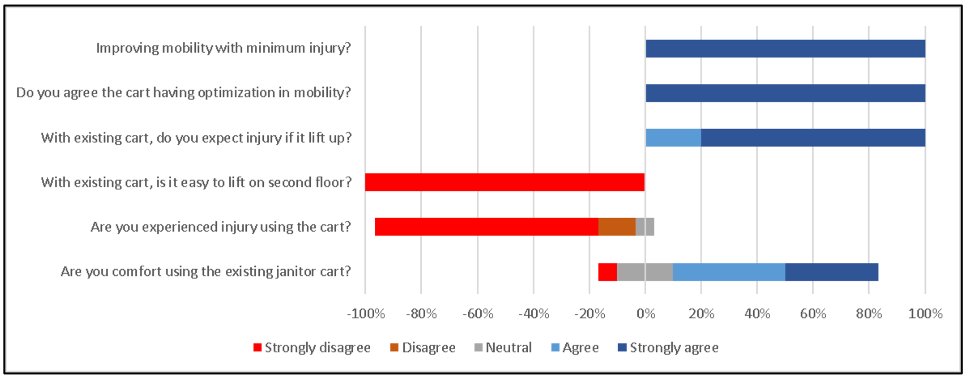


Figure 4.1 Response on 1st survey form

The responses obtained from the survey form shows the perceptions of design and optimization of attachment on janitor cart in FTK UTeM. The cleaning staffs gender shows that 7 of them were males and 8 were females. Participants also agreed that the existed janitor cart in FTK UTeM is comfort to use. Using the janitor cart on the ground floor, majority shown that there are no possible injuries happen when they use the janitor cart. Plus, most of the respondents are strongly disagreed that the existing janitor cart are possible to lift up to second floor which directly strongly agreed to occur possible injury on body part if they insisted to bring the cart on second floor. The results shows that they were strongly agreed if there is optimization on the cart for enhance mobility to lift on second floor for cleaning services along with minimizing the injury during the process.

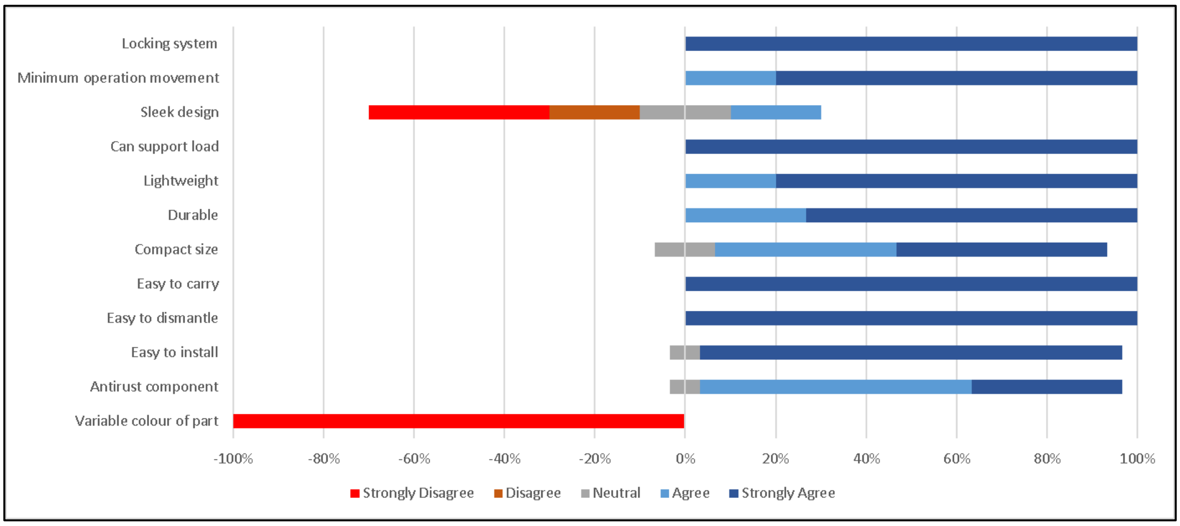


Figure 4.2 Response on 2nd survey form

4.3 Selection Method

4.3.1 Pugh Method Selection

Table 4.2 Results of Pugh method selection

Criteria	Design A	Design B	Design C
Antirust component	+	+	+
Compact size	-	+	+
Lightweight	0	+	+
Durability	+	-	-
Minimum operation	+	-	-
Ease operation	+	0	0
Cost	0	+	0
Sum +	4	4	3
Sum 0	2	1	1
Sum -	1	2	2
Net score	3	2	1
Rank	1	2	3

Based on the results of the Table 4.2 Pugh method selection above, it shows that the overall net score gains from each three design with three points for design A, which takes for the first place and followed by design B and C with net score two and one repetitively. This method shows the most important contributes in design which must be align with customers need. The design also needs to fulfill the requirements on acts as an attachment that can helps the cleaning staffs to carry the janitor cart on second floor. Plus, the design A is more reliable and functionable to use by them during cleaning services. When comparing the design, Design A is the most relevant choices.

4.3.2 House of Quality

Table 4.3 Resulted of HOQ

Competitor 1	**Competitor 2**	**Competitor 3**
4	3	4
1	2	1
1	2	1
5	3	1
5	2	1
5	4	1
5	5	5
3	2	5
1	3	5
2036	1836	1286

According to the outcomes of the analysis carried out using the house of quality technique, there are three designs that have been evaluated, and have been determined the highest scores among the design. It is required to investigate the relationship between Customer requirements and technical requirements in order to make these evaluations more reliable. As shown in the Table 4.3 Result of HOQ above, competitor 1 achieved the highest score of 2036, while competitor 2 and 3 obtained scores of 1836 and 1286 to position them in second and third place, respectively. From there, the selected design should be inspired from the design in Competitor 1 because it quite related to the requirements of this project. The selected design will be analyzed and undergo simulation on static structural analysis and optimization on focusing in minimizing the mass and maintaining the safety factor of the product.

4.4 Technical drawing for base design A

The technical drawing of the design A as shown in Figure 4.3 below are the design that has been selected according to the evaluation from Pugh Method Selection and House of Quality analysis diagram. From the conceptual initial design of the attachment part, it has been created in Catia CAD software as technical drawing for the base design.

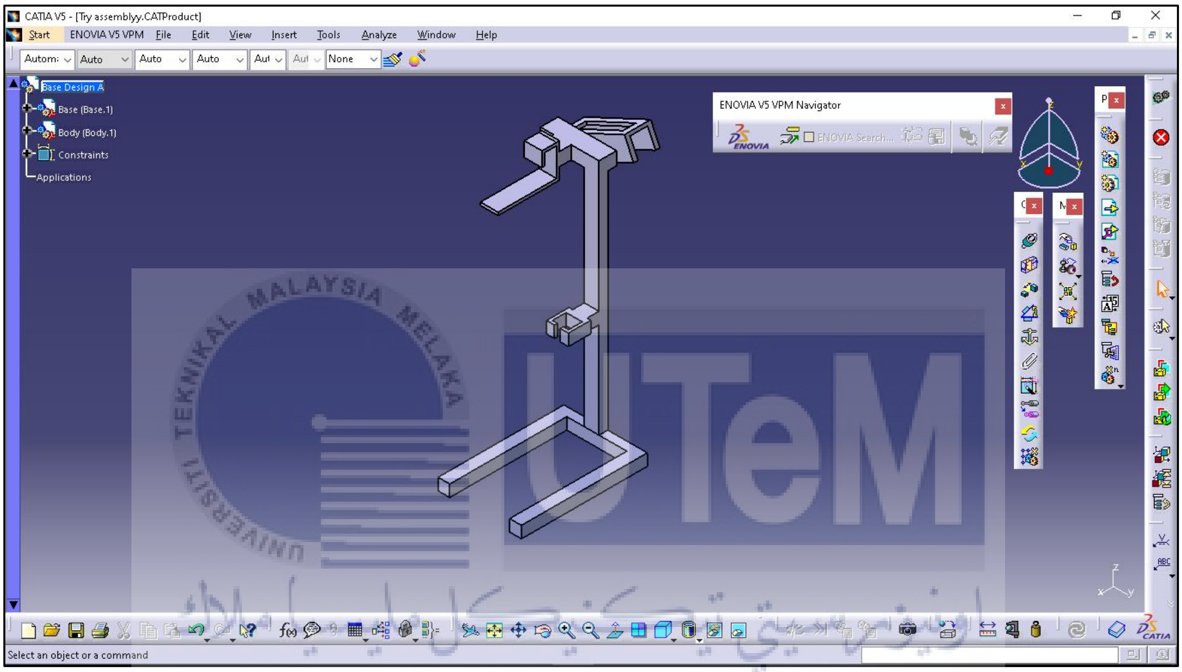


Figure 4.3 Base Design A technical drawing

4.5 Simulation Setup

The design that has been construct from the software CATIA V5R21, then it has been save and export for analysis simulation process. The analysis process of the design has been simulated using Ansys Inspire 2022.2.1. Several setup parameters have been made using this software in order to achieve the data and findings on the design of the attachment part for janitor cart.

4.5.1 Partition and Design Space configuration

Based on the Figure 4.4 and 4.5 below, it shows that the configuration for the determined the partition process and design space process on the design part. The partition is to separate the unchangeable surface that can apply parameters for analysis process. Thickness of the partition selected part has been set to 1 mm. That surface also excludes from affect during optimizing process. The design space has been applied on the whole body which will indicates the desirable part to be analyzed.

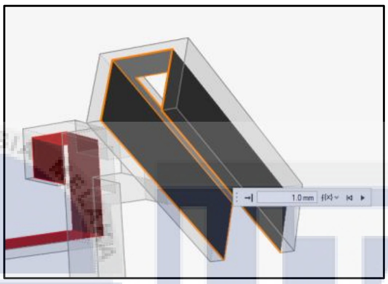


Figure 4.4 Partition setup

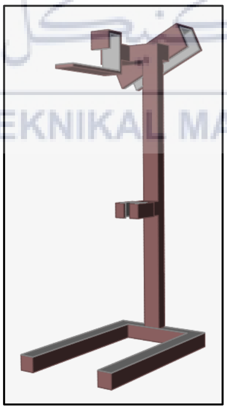
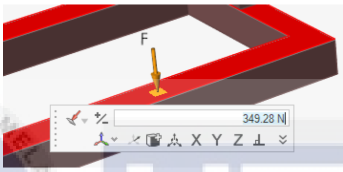
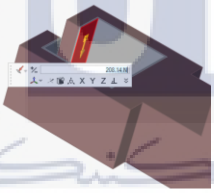
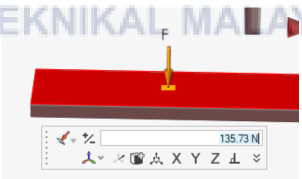
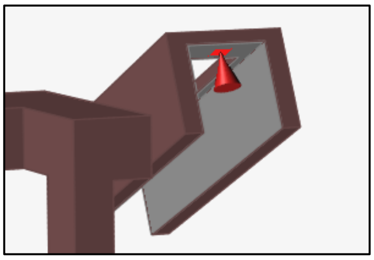


Figure 4.5 Design space setup

4.5.2 Applying Load and Support

The Table 4.4 below shows the configuration setup for the load and support on the design. All the parameters for load and support have been determined and placed on the selected partition surface. The variable load input indicates the location of the part placed on the janitor cart during attached which has been determined from the technical drawing of the cart.

Table 4.4 Load and Support configuration

Setup	Photo	Value
Support		
Load		349.28N
Load		208.14N
Load		135.73N
Support		

4.5.3 Applying Material for Analysis Process

The material that will be undergo the analysis process is as mentioned on the methodology section. The design part will be applied with those material for each process. The total mass of the design once material has been applied has been recorded. The analysis process is to determine the suitable and desirable material that will withstand to attach with janitor cart and lift the load in order to climb on second floor. The contact surface also important in order to avoid errors during simulation process and obtained optimum data results.

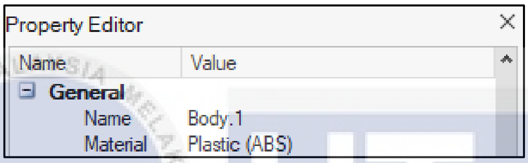


Figure 4.6 Applying material on the part design

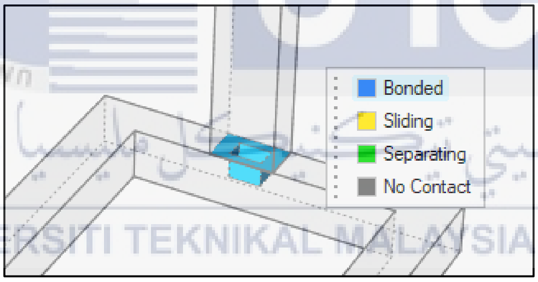
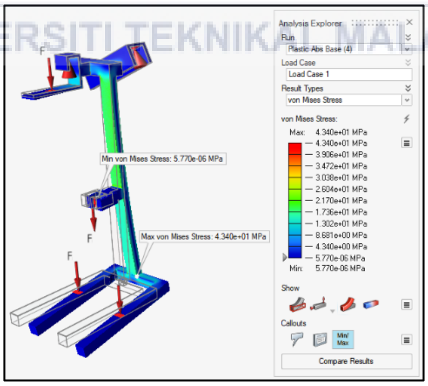


Figure 4.7 Determined the contact surface

4.6 Design results for each material

4.6.1 Design analysis for ABS Plastic

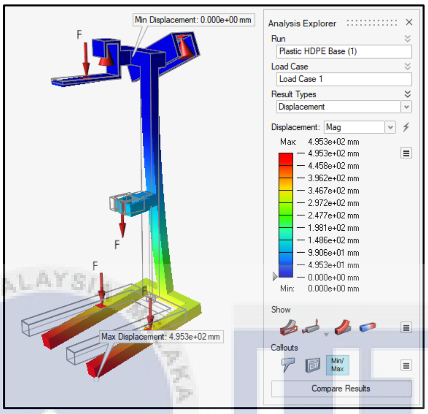
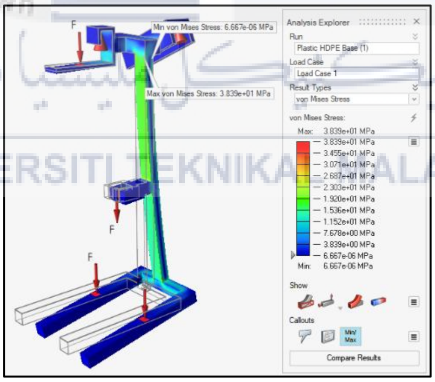
Table 4.5 Result for base design of ABS Plastic

Type of results	Simulation configuration	Maximum Value	Minimum Value
Displacement		$3.067e^{+02}$ mm	0 mm
Von Mises Stress		$4.340e^{+01}$ MPa	$5.770e^{-06}$ MPa

Based on the Table 4.5 above shows the results of material ABS Plastic for base design displacement deformation is $3.067e^{+02}$ mm while maximum value of Von mises stress is $4.340e^{+01}$ MPa.

4.6.2 Design analysis for HDPE Plastic

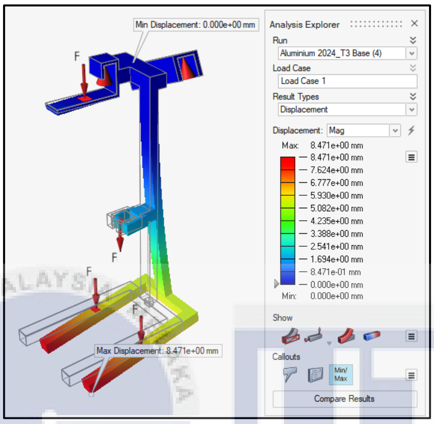
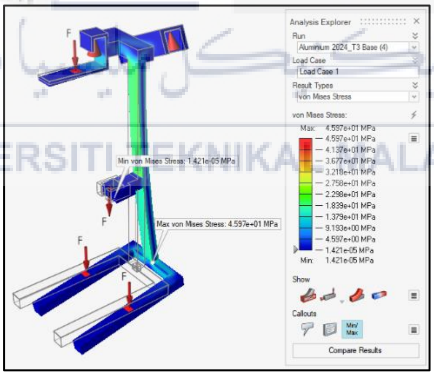
Table 4.6 Result for base design of HDPE Plastic

Type of results	Simulation configuration	Maximum Value	Minimum Value
Displacement		$4.953e^{+02}$ mm	0 mm
Von Mises Stress		$3.839e^{+01}$ MPa	$6.667e^{-06}$ MPa

Based on the Table 4.6 above shows the results of HDPE Plastic for base design displacement deformation is $4.953e^{+02}$ mm and maximum value of Von mises stress is $3.839e^{+01}$ MPa.

4.6.3 Design analysis for Aluminum (2024 T3)

Table 4.7 Result for base design of Aluminum (2024 T3)

Type of results	**Simulation configuration**	**Maximum Value**	**Minimum Value**
Displacement		8.471 mm	0 mm
Von Mises Stress		$4.597e^{+01}$ MPa	$1.421e^{-05}$ MPa

Based on the Table 4.7 above shows the results of Aluminum (2024 T3) for base design displacement deformation is 8.471 mm and the maximum value of Von mises stress is $4.597e^{+01}$ MPa.

4.7 Optimization Setup

Based on the Figure 4.8 below shows the setup for optimization process. The parameters have been set before undergo the optimization for enquired the results of optimized design. The setup has been set to achieve minimize the weight while maintain the stiffness of the attachment part. Topology optimization with maximize stiffness has been setup in this parameter. The % of Total Design Space has been set to 30% with minimum thickness of 11mm and maximum thickness are 11.683mm. The gravity simulation also has been applied because the operation of the part needs to lift the janitor cart using stairs.

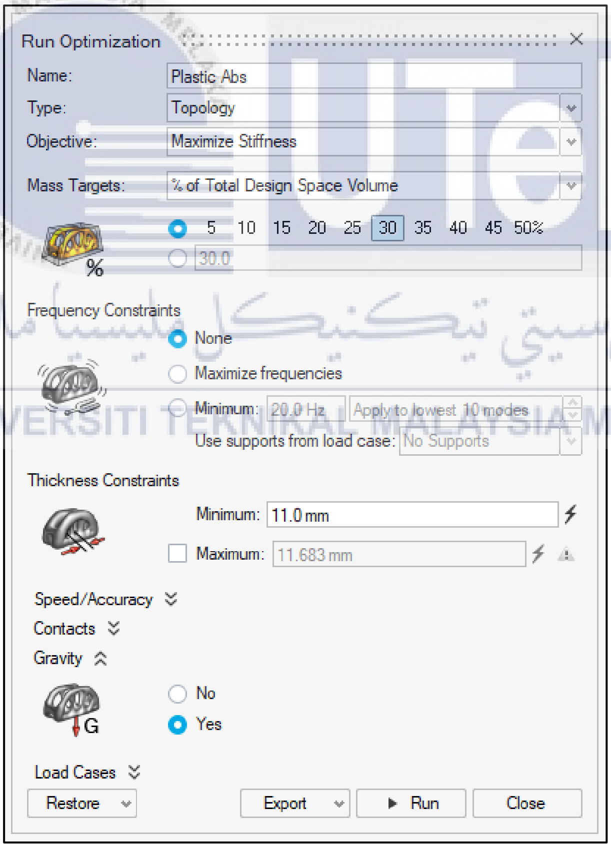


Figure 4.8 Topology optimization setup

4.7.1 Shape Control Configuration

As the Figure 4.9 and Figure 4.10 below shows the setup on the design for optimization process. The symmetry control indicates the results for symmetrical optimized design based on the parameters that have been set. The draw direction has been set on the design spaces which to part plane between the haves which lies on outside design space. Each setup is important for optimizing design to enable obtaining possible minimize weight while maintain its stiffness.

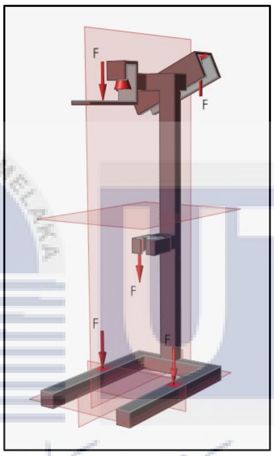


Figure 4.9 Applying symmetry control on design

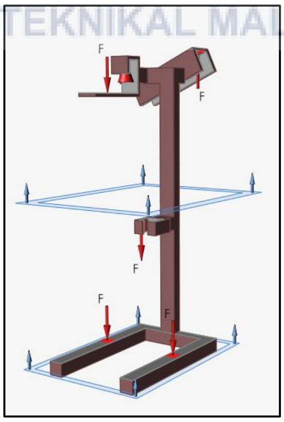
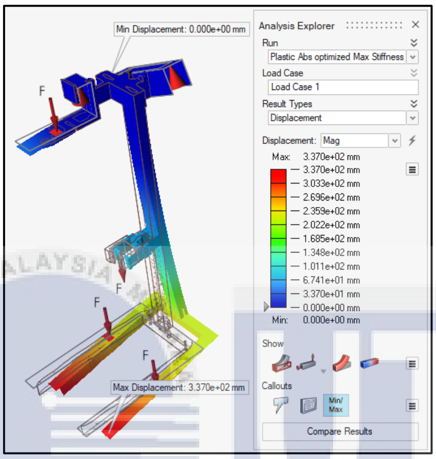
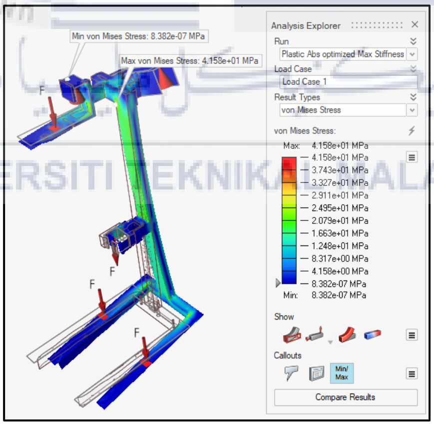


Figure 4.10 Applying draw direction on design

4.8 Analysis for Optimized Design

4.8.1 Optimized design analysis for ABS Plastic

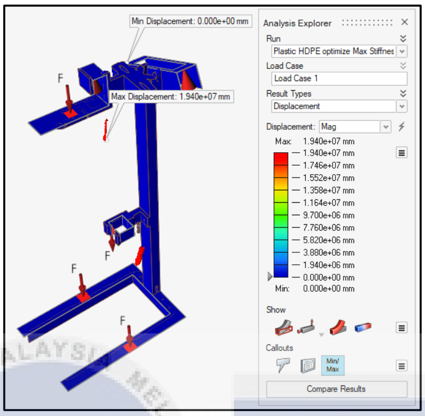
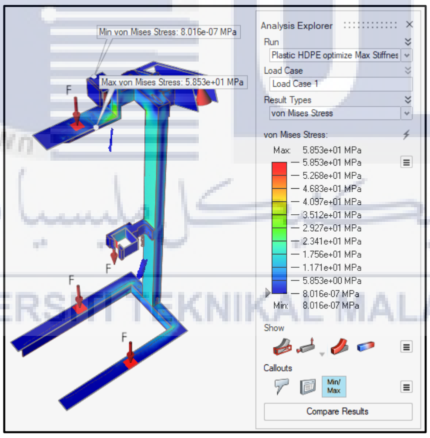
Table 4.8 Results for optimized design ABS Plastic

Type of results	Simulation configuration	Maximum Value	Minimum Value
Displacement		$3.370e^{+02}$ mm	0 mm
Von Mises Stress		$4.158e^{+01}$ Mpa	$8.382e^{-07}$ Mpa

Based on the Table 4.8 above shows the results of ABS Plastic for optimized design displacement deformation is $3.370e^{+02}$ mm and the maximum value of Von mises stress is $4.158e^{+01}$ Mpa.

4.8.2 Optimized design analysis for HDPE Plastic

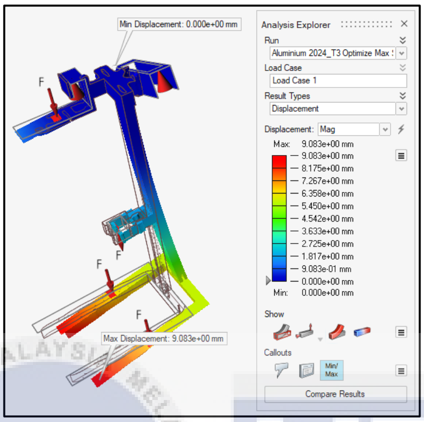
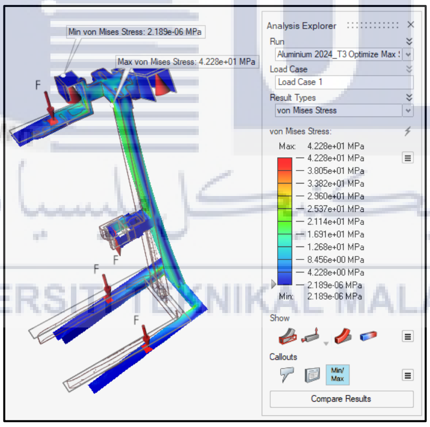
Table 4.9 Result for optimized design HDPE Plastic

Type of results	**Simulation configuration**	**Maximum Value**	**Minimum Value**
Displacement		$1.940e^{+07}$ mm	0 mm
Von Mises Stress		$5.853e^{+01}$ Mpa	$8.016e^{-07}$ Mpa

Based on the Table 4.9 above shows the results of HDPE Plastic for optimized design displacement deformation is $1.940e^{+07}$ mm and maximum value for Von mises stress is $5.853e^{+01}$ Mpa.

4.8.3 Optimized design analysis for Aluminum (2024-T3)

Table 4.10 Results for optimized design Aluminum (2024-T3)

Type of results	**Simulation configuration**	**Maximum Value**	**Minimum Value**
Displacement		9.083 mm	0 mm
Von Mises Stress		$4.228e^{+01}$ Mpa	$2.189e^{-06}$ Mpa

Based on the Table 4.10 above shows the results of Aluminum (2024 T3) for optimized design displacement deformation is 9.083 mm and maximum value for Von mises stress is $4.228e^{+01}$ Mpa.

4.8.4 Calculation of Safety Factor

Calculation for the safety factor on the simulated analysis is to determine the ratio of design structure absolute strength. The calculation has been calculated by using formula on APPENDIX E.

Table 4.11 Safety factor for base design

Type of material	**Material Strength, Pa**	**Ultimate Stress, Pa**	**Safety Factor**
ABS Plastic	$4.5e^{+07}$	$4.340e^{+07}$	1.037
HDPE Plastic	$4.0e^{+07}$	$3.839e^{+07}$	1.042
Aluminum (2024-T3)	$2.758e^{+08}$	$4.597e^{+07}$	1.631

Table 4.12 Safety factor for optimized design

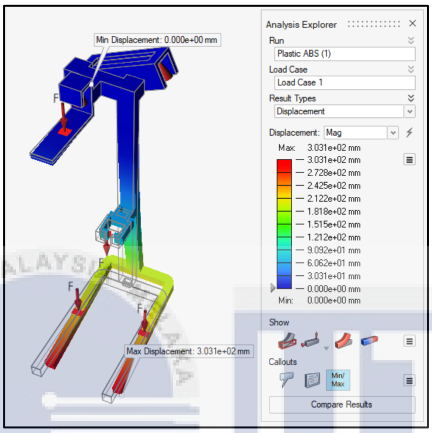
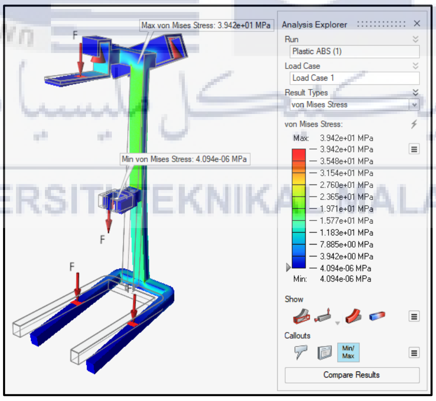
Type of material	**Material Strength, Pa**	**Ultimate Stress, Pa**	**Safety Factor**
ABS Plastic	$4.5e^{+07}$	$4.158e^{+07}$	1.082
HDPE Plastic	$4.0e^{+07}$	$8.853e^{+07}$	0.683
Aluminum (2024-T3)	$2.758e^{+08}$	$4.228e^{+07}$	1.773

Based on the Table 4.11 above shows the calculated value of safety factor in base design. Aluminum (2024 T3) material have the highest value of the safety factor with 1.631 while material ABS Plastic and HDPE Plastic have slightly different value of safety factor. However, in Table 4.12 above shows the material of Aluminum (2024 T3) also have the highest value of safety factor among others material. Hence, the material for HDPE Plastic has the lowest safety factor for optimized design with 0.683. which means the material is tend to fail greater than the other material for minimum mass of material of the attachment part compared to the others material. The value of safety factor for material ABS Plastic in optimized design is 1.082 which have significantly increased when unnecessary material has been removed.

4.9 Final design

4.9.1 Analysis ABS Plastic final design

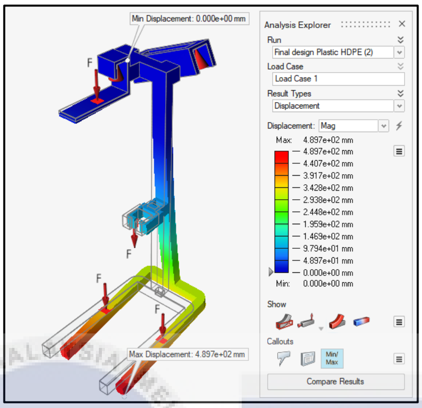
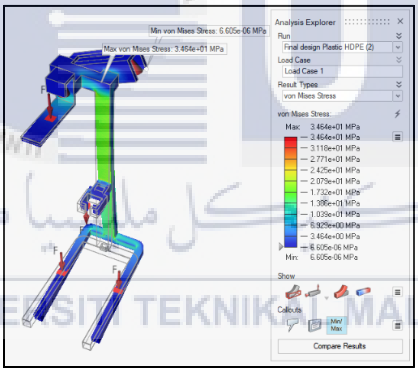
Table 4.13 Result of ABS Plastic final design

Type of results	**Simulation configuration**	**Maximum Value**	**Minimum Value**
Displacement		$3.031e^{+02}$ mm	0 mm
Von Mises Stress		$3.942e^{+01}$ Mpa	$4.094e^{-06}$ Mpa

Based on the Table 4.13 above shows the results of ABS Plastic for final design displacement deformation is $3.031e^{+02}$ mm and maximum value for Von mises stress is $3.942e^{+01}$ Mpa.

4.9.2 Analysis HDPE Plastic final design

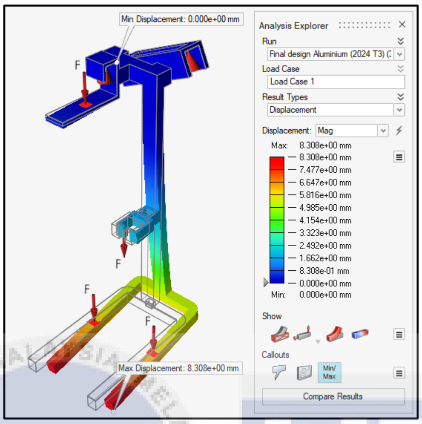
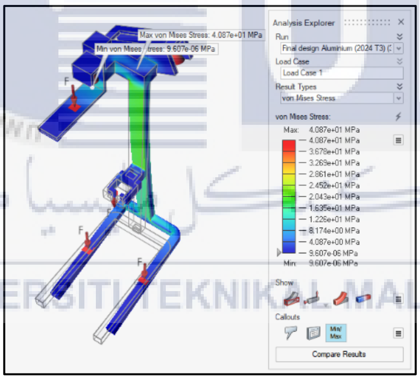
Table 4.14 Result of HDPE Plastic final design

Type of results	**Simulation configuration**	**Maximum Value**	**Minimum Value**
Displacement		$4.897e^{+02}$ mm	0 mm
Von Mises Stress		$3.466e^{+01}$ Mpa	$6.605e^{-06}$ Mpa

Based on the Table 4.14 above shows the results of HDPE Plastic for final design displacement deformation is $4.897e^{+02}$ mm and the maximum value for Von mises stress is $3.466e^{+01}$Mpa.

4.9.3 Analysis Aluminum (2024 T3) final design

Table 4.15 Result of Aluminum (2024 T3) final design

Type of results	Simulation configuration	Maximum Value	Minimum Value
Displacement		8.308 mm	0 mm
Von Mises Stress		$4.087e^{+01}$ Mpa	$9.607e^{-06}$ Mpa

Based on the Table 4.15 above shows the results of Aluminum (2024 T3) for final design displacement deformation is 8.308 mm and the maximum value for Von mises stress is $4.087e^{+01}$Mpa.

4.9.4 Safety factor for final design

Table 4.16 Safety factor for final design

Type of material	Material Strength, Pa	Ultimate Stress, Pa	Factor of safety
ABS Plastic	$4.5e^{+07}$	$3.942e^{+07}$	1.14
HDPE Plastic	$4.0e^{+07}$	$3.464e^{+07}$	1.15
Aluminum (2024-T3)	$2.758e^{+08}$	$4.087e^{+07}$	1.83

Based on the Table 4.16 above shows the results of calculated safety factor for those material in final design. The results show the Aluminum (2024 T3) have the highest value of safety factor 1.83 among others material. However, for the final design analysis, the safety factor for ABS Plastic and HDPE Plastic material have slightly different in safety factor value which is 1.14 and 1.15 respectively.

4.10 Technical drawing for final design

An orthographic view perspective display of the attachment part design on front, left and top views. It also consists of 45 degrees illustrated diagram of image in isometric view. The scale of the drawing has been set to 1:7.

4.10.1 Ortographic view for final design

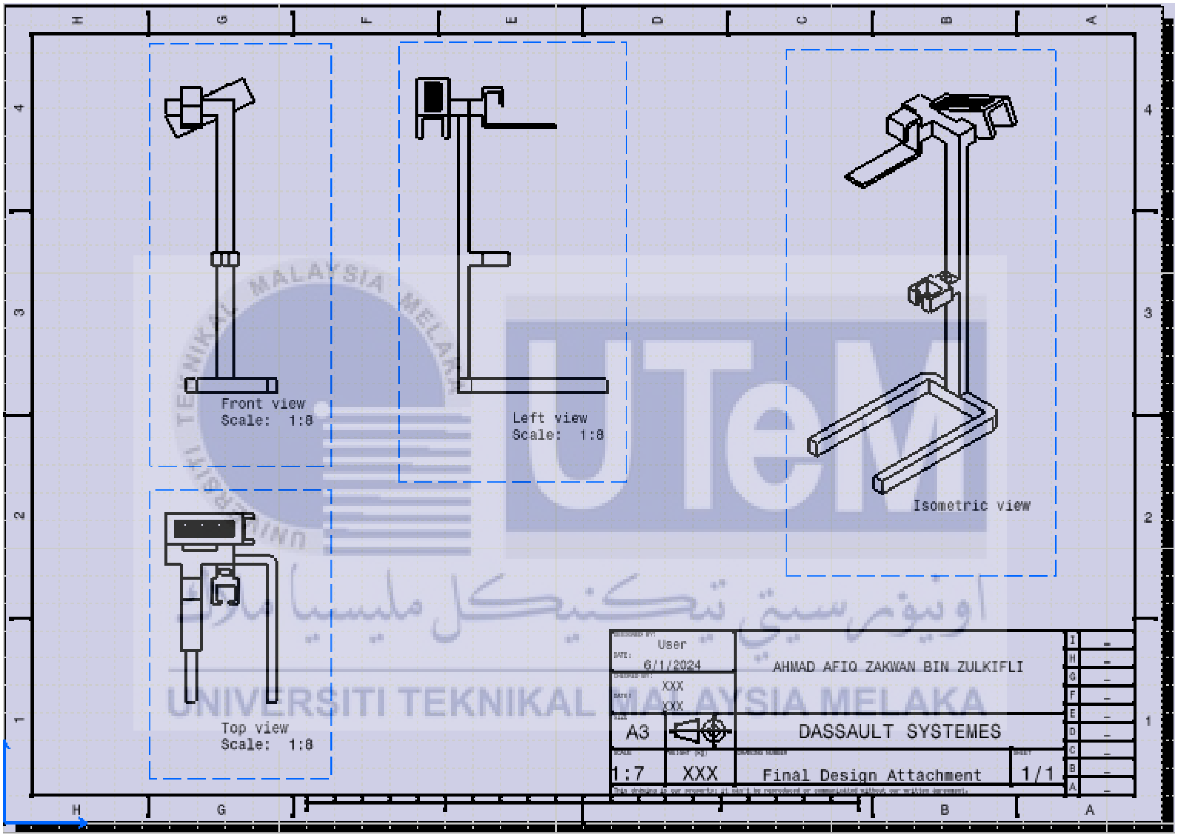


Figure 4.11 Orthographic view final design attachment

As the given Figure 4.11 above shows the final design of the attachment view for mobility on the janitor cart. The design of the cart has been refined from the simulated Topology Optimization on reducing the unnecessary mass on the part. It comes with roller which functioned to reduce the movement friction between the stair rail. Hence, it will ease the pushing movement during lifting the janitor cart using stairs. Plus, the design has been redefined from the initial base design with an optimum mass for cleaning purposes.

4.11 Observation on safety factor

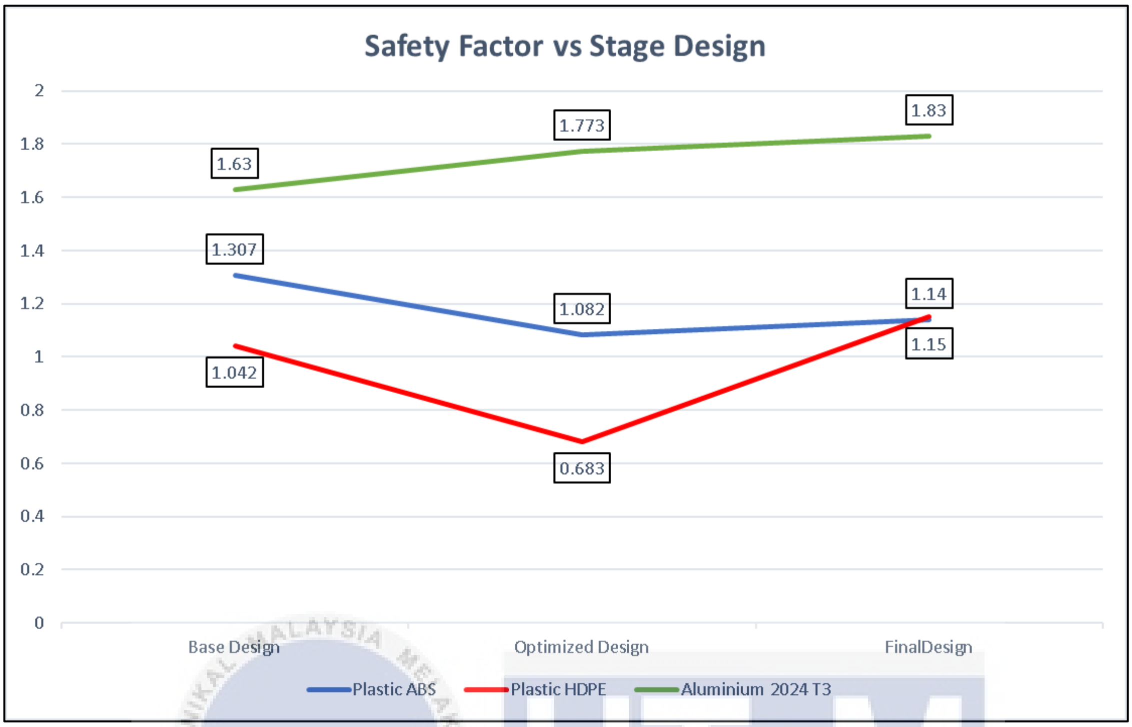


Figure 4.12 Graph for Safety factor value vs Stage design

According to the illustrated Figured 4.12 above shows the pattern of the evaluated safety factor value from simulated analysis process which has been used in Ansys Inspire 2021.2.1 software. The graph shows the evaluated safety factor based on the static structural test analysis occurred on each design stage. Material for Aluminum (2024 T3) have the highest value of safety factor on all stages. It shows that the material easily can withstand the load on the janitor cart for mobility purposes. However, the material HDPE Plastic have the lowest pattern of on all stage which shows that the material might be easily fail for support all the load on the janitor cart. Indirectly, by referring the results above shows that ABS Plastic have the optimum pattern among all stages which it can be more reliable for supporting load even in minimum mass of the attachment part design.

4.12 Percentage mass differences in design

Table 4.17 Mass differences between design

Material	Base Design, kg	Optimized Design, kg	Differences, %
ABS Plastic	4.764	2.278	52.18
HDPE Plastic	4.27	1.998	53.21
Aluminum (2024 T3)	12.449	5.945	52.25

Based on the Table 4.17 above shows the percentage of mass differences for each material. The calculation formula for mass differences can be referred on APPENDIX G. The mass differences evaluated between the base design and optimized design. From there, material HDPE Plastic has the highest percentage for mass difference with 53.21% while for the ABS Plastic and Aluminum (2024 T3) are 52.18% and 52.25% respectively. From there, it shows that the optimization process in reducing unnecessary material on the attachment part while maintaining the stiffness of the part are most reliable for ABS Plastic due to the total mass is acceptable for designing as an attachment part. Hence it can support the load for mobility purpose on lifting the janitor cart on second floor.

4.13 Summary

According to the results and discussion of the implementing the design development, the design ideas have been created from the survey evaluation. The survey questions which asked for criteria design requirement need for the attachment part. The evaluation of HOQ meets the design creation from the customer requirements. According to the material application which has been undergo various design stages, comparison between those material selection. According to the pattern of the results on Finite Element Analysis of maximum Displacement and Von mises stress, ABS Plastic shows the optimum material for the attachment part. The evaluation of safety factor also shows that ABS Plastic are efficient material to withstand the load applied for base, optimized and final design. Hence, the further process of the developing attachment part on the janitor cart will be discussed on Chapter 5.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The results of the study were reported in this chapter, which also as a proposal for further research in the future. In general, a significant number of researches has been done into the designing an attachment on the janitor cart by using QFD evaluation system and Finite Element Analysis for determine the load effect on the design and determining the safety factor of the design. The conclusion section consists of information such as an overview of the research and summary based on the obtained results. In the recommendation section, it is urged that this project be further evaluated and developed.

5.2 Conclusion

In this research, the first aim is to conduct several study surveys on the mobility of the attachment cart in order to lift up to second floor by using stairs. The scope of the building setting is in Technology Campus, UTeM because it lacks of facility such as lift during cleaning services. Overall, the designing process in developing an attachment of the part using Pugh Method Selection and House of Quality system. The design of the part has been created in CATIA V5 R21 software and has been analyze the Linear Static Structural analysis in Ansys Inspire 2021.2.1 software in order to determine the simulated results when all the parameters load has been applied on the design.

The obtained simulated finding on Displacement and Von Mises Stress, a comparison has been made by different type of material. The findings have been evaluated to determine the factor of safety values. Hence, the optimization process is to determine the total mass reduce while maintain the capability of the attachment part to support the load. The final design has been created based on the illustration for optimized design and undergo the simulated analysis on the part.

Based on the study on mobility attachment by using stairs, it helps the users for many purposes which it minimizing time and easily use the part due to durability on supporting the load. The material that uses for the part also important for maintaining the safety precaution when using the attachment part. For this reason, it required for further studies to investigate and analyze various material that are more suitable with this attachment part.

5.3 Recommendations and future developement

Based on the data obtained, this project can be improved by this recommendation for future development:

- Increasing the dimension of the base design before undergo the optimization process to obtain accurate results in minizing mass and maintaing the stiffness of the design.
- Improving the design of the roller to obtain smooth movement using the stair's rail.
- Determine some of new materials that suitable to be considered in designing and undergo analysis for simulated the effect when applying load for manufacturing purpose.

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APPENDICES

APPENDIX A Survey Form Questionaire

Survey Form on Janitor Cart in FTK UTeM

Borang Kaji Selidik Troli Pembersihan di FTK UTeM

I am Ahmad Afiq Zakwan Bin Zulkifli final year from BMMA University Technical Malaysia Melaka. This survey is to study the mobility of janitor cart in FTK UTeM for going to second floor. We appreciated your cooperation to answer this survey.

Saya Ahmad Afiq Zakwan Bin Zulkifli pelajar tahun akhir dari BMMA Universiti Teknikal Malaysia Melaka. Tinjauan ini adalah untuk mengkaji mobiliti troli pembersihan di FTK UTeM untuk ke tingkat dua. Kami menghargai kerjasama anda untuk menjawab tinjauan ini.

1. Gender (*Jantina)*

Male (Lelaki)	Female (Perempuan)

2. Age (*Umur*)

16-20	21-25	26-30	31-35	36-40	41 above

3. Working hours (*Masa bekerja*)

2h (2j)	4h (4j)	6h (6j)	8h (8j) above

4. Working experienced (*Pengalaman pekerjaan*)

6 months below	1 year	2 years	3 years above

5. Are you comfort by using existed janitor cart? (*Adakah anda selesa menggunakan troli pembersihan yang sedia ada?)*

1	2	3	4	5

6. Are you experienced injury/illness on body part during cleaning services? (*Adakah anda mengalami sakit/cedera pada badan semasa melakukan kerja pembersihan?)*

1	2	3	4	5

7. Types of injury/illness on body part? (*Jenis sakit/cedera pada tubuh badan?)*

Sakit Belakang	Sakit Lutut	Sakit Lengan	Sakit Pinggang	Lain-lain

When focusing the cleaning task in Factory 3 in FTK UTeM, there is no facilities such as lift or travelator. Answer the question below:

Apabila tugas pembersihan dijalankan di Kilang 3 di FTK UTeM, dimana tiada kemudahan seperti lif atau pengembara. Jawab soalan di bawah:

8. With existing janitor cart, is it easy to lift up to second floor? (*Penggunaan troli pembersihan semasa, adakah senang untuk ke tingkat 2?)*

1	2	3	4	5

9. By using existing janitor cart, do you expect injury by lift to second floor? (*Dengan troli pembersihan semasa, adakah sebarang kecedaran akan berlaku jika di angkat ke tingkat 2?*

1	2	3	4	5

10. If there is optimization on the mobility of the cart, do you agree? (*Jika terdapat penambahbaikan mobiliti troli pembersihan, adakah anda setuju?)*

1	2	3	4	5

11. Improving mobility of the cart with minimum injury, do you agree? (*Penambahbaikan mobiliti troli dengan minima kecederaan, adakah anda setuju?)*

1	2	3	4	5

12. Suggest some recommendation on mobility of janitor cart in FTK UTeM. (*Senaraikan cadangan terhadap mobiliti troli pembersihan di FTK UTeM.)*

APPENDIX B Survey Question On Design Criteria of Attachment

Survey Questions

Description

This survey created for us to know for customer's needs and workers for an attachment on janitor cart.

An attachment on janitor is an ensure for cleaning workers by focusing on ease their cleaning services on second floor by using stairs because lack of facilities such as lift in building setting on Faculty Technology UTeM on aspects as ability to lift upstairs. Here, we would like to ask some question for our project in making it a desirable attachment on janitor cart using stairs

We're made a list of some of improvements that might need to have for the attachment.

Tick (/) based on your opinion.

1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree

No		1	2	3	4	5
1	Variable colour of the part					
2	An antirust component					
3	Easy to install					
4	Easy to dismantle					
5	Easy to carry on cart					
6	Compact size					
7	Durable					
8	Lightweight					
9	Can support cleaning load					
10	Sleek in design					
11	Minimum operation movement					
12	Locking system					

Please list any other features you would like to on the attachment part.

....

....

Would you be wisely use more often for the improvements you value with 4 or 5 rating are available on the market?

☐ Yes

☐ No

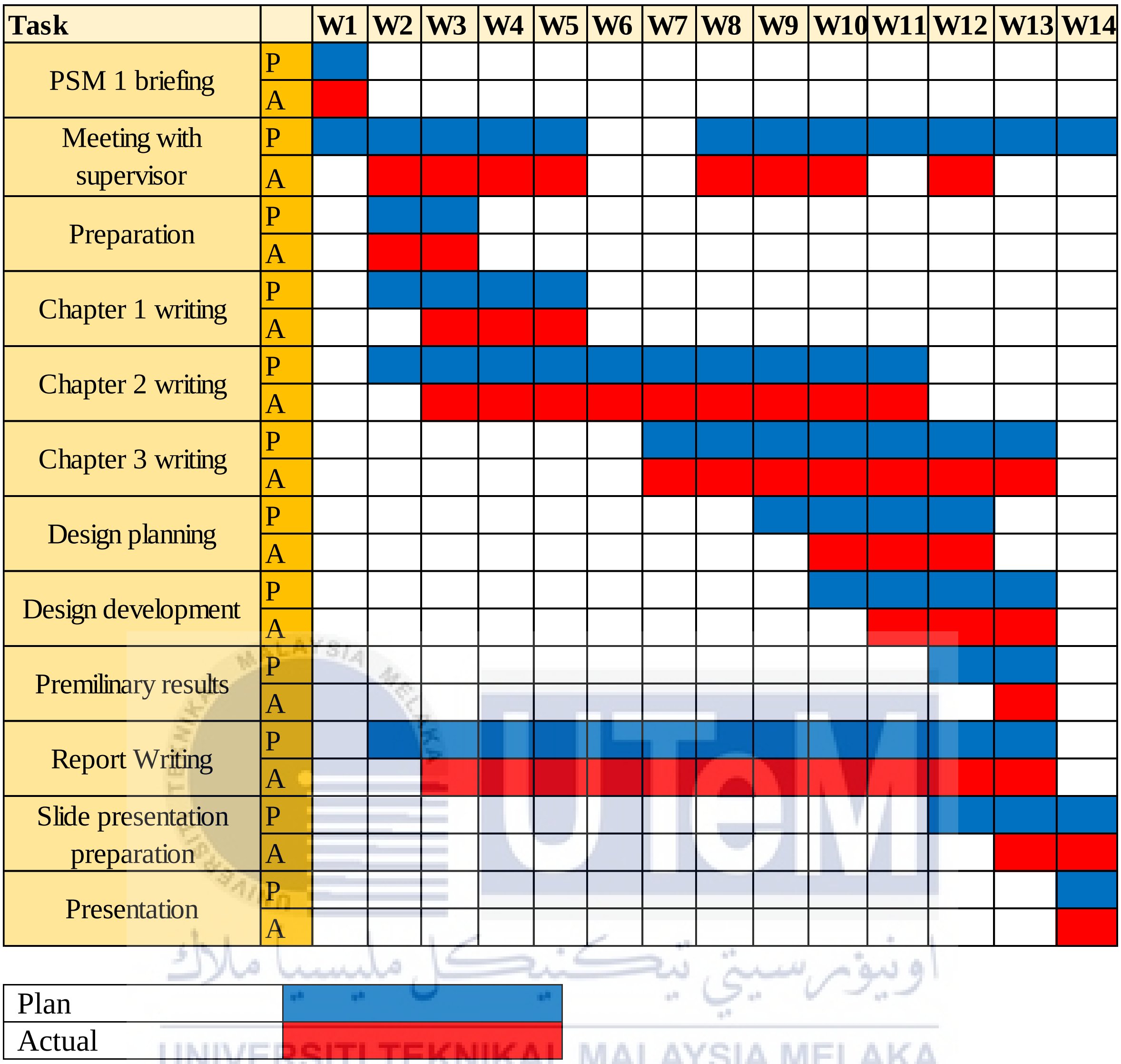
How frequent do you experience cleaning service or observe cleaning staffs undergo cleaning on second floor using janitor cart?

☐ Almost everyday

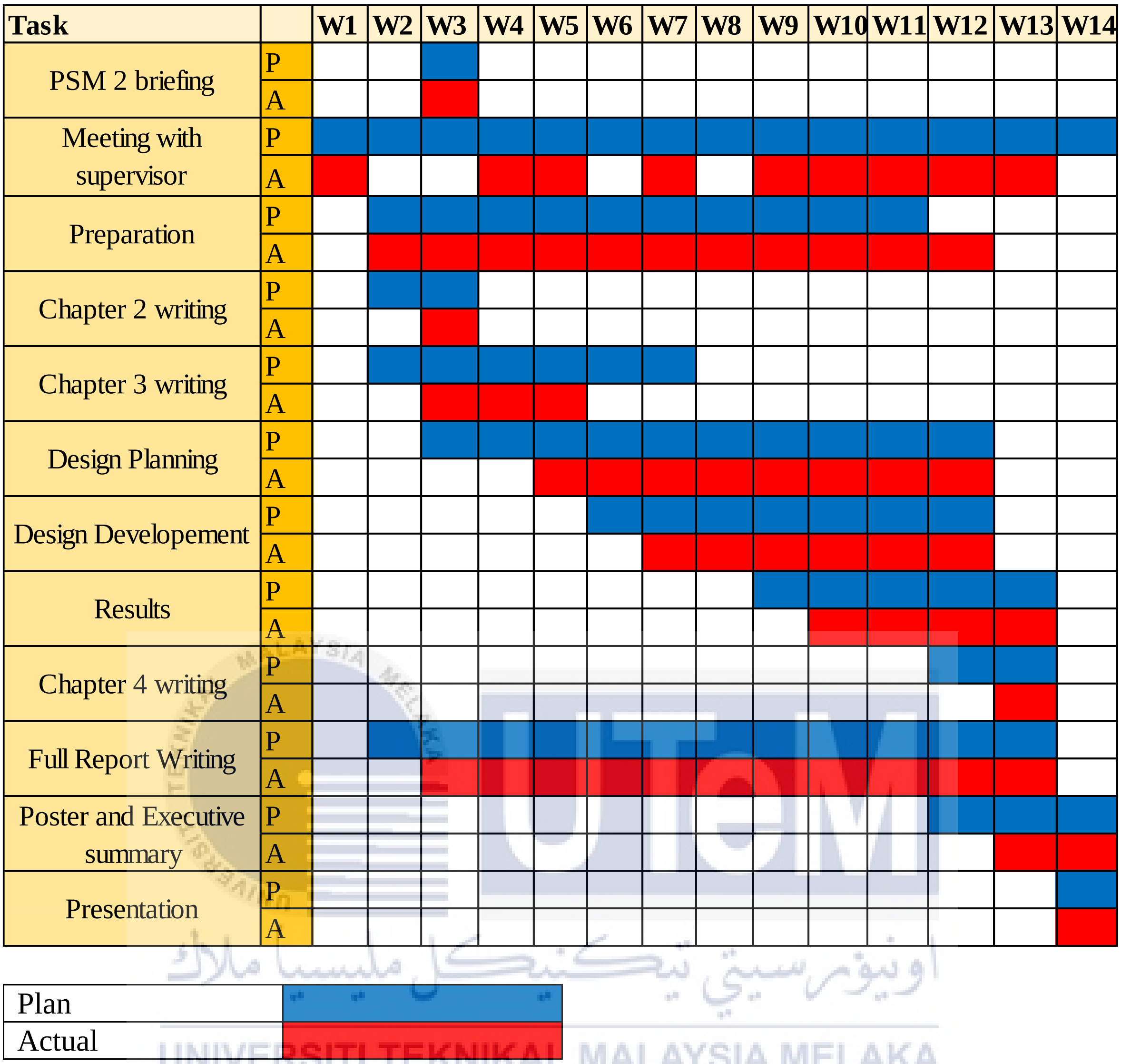
☐ Few times per week

☐ Few times in month

APPENDIX C Gantt Chart for PSM 1



APPENDIX D Gantt chart for PSM 2



APPENDIX E Formula for weight

$$\text{Weight, N} = Mass\ (kg) \times Gravity\ (ms^{-2})$$

APPENDIX F Formula safety factor

$$\text{Factor of safety, FOS} = \frac{Yield\ Strength}{Design\ Stress}$$

APPENDIX G Formula Mass differences

$$\text{Mass differences, \%} = \frac{(Mass\ base - Mass\ optimized)}{Mass\ base}$$

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Tuan

PENGKELASAN TESIS SEBAGAI TERHAD BAGI TESIS PROJEK SARJANA MUDA

Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh **LIMA** tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

Nama pelajar: AHMAD AFIQ ZAKWAN BIN ZULKIFLI (B092010378)
Tajuk Tesis: DESIGN AND OPTIMIZATION OF MOBILITY ATTACHMENT ON JANITOR CART IN CAMPUS TECHNOLOGY UTEM.

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"
"KOMPETENSI TERAS KEGEMILANGAN"

Saya yang menjalankan amanah,

MOHD HARRIS FADHILAH BIN ZAINUDDIN
Penyelia Utama/ Pensyarah Kanan
Fakulti Teknologi dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka