Design of a Glass Wall Cleaning Mechanism

By

Chua Ken Seng

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JUNE 2010

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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Approved by,

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(Mr. Azman Zainuddin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsibility for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herin have not been undertaken or done by unspecified sources or persons.

CHUA KEN SENG

Abstract

Cutting down the maintenance cost, reduce the cleaning time and eliminates air pollution are the 3 main objectives set in this project entitle “To Design a glass wall cleaning mechanism”. The challenge here is to design a cleaning mechanism that will clean the outer wall of the glass panel of the Universiti Teknologi PETRONAS academic block while fulfilling the 3 objectives. Thus, a series of criteria were set, and justified, conceptual model to represent the criteria is designed and given verdict before the real product is being design in details. The final product of this project is a detail design of a cleaning mechanism that is supported by a supporting system which will be move across the rooftop of the academic building. Then the final product is being analyzed for the force distribution, the cost comparison between the contractor service and implement the mechanism and lastly to propose some recommended work into the project for further research .

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to my supervisor, Mr Azman Zainuddin , for his direction, assistance, guidance, and useful information he had given to me to go through this Final Year Project. From time to time, he had given me recommendations and ideas that are very valuable for this project. Without his help, my project would not have take off successfully.

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CHUA KEN SENG (8650)

Universiti Teknologi PETRONAS

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Glass is the most used alternative material for construction of Universiti Teknologi PETRONAS (UTP) academic blocks. Glass panels are installed as walls onto the academic block s of UTP. The glass size installed is divided into 2 types: 2.4m (length) by 0.8m (width) and 3.35m (length) by 0.8m (width). Among the advantages of glass walls are the building is exposes to full penetration of sunlight to the buildings thus making the office area look brighter , modern and elegance looking building and also eliminate the cost repainting the wall as encounter by conventional bricks wall. Therefore, in order to keep the outer glass-walls panel debris free and spotless; UTP management needs to clean the glass panels regularly. Cleaning the glass-wall is not an easy task as it involves many types of equipment such as mobile sky lift in order for the cleaner to clean the wall. Due to all the difficulties involve, therefore this project “To Design a Glass Wall Cleaning Mechanism” is initiated to solve all these difficulties.

1.2 PROBLEM STATEMENT

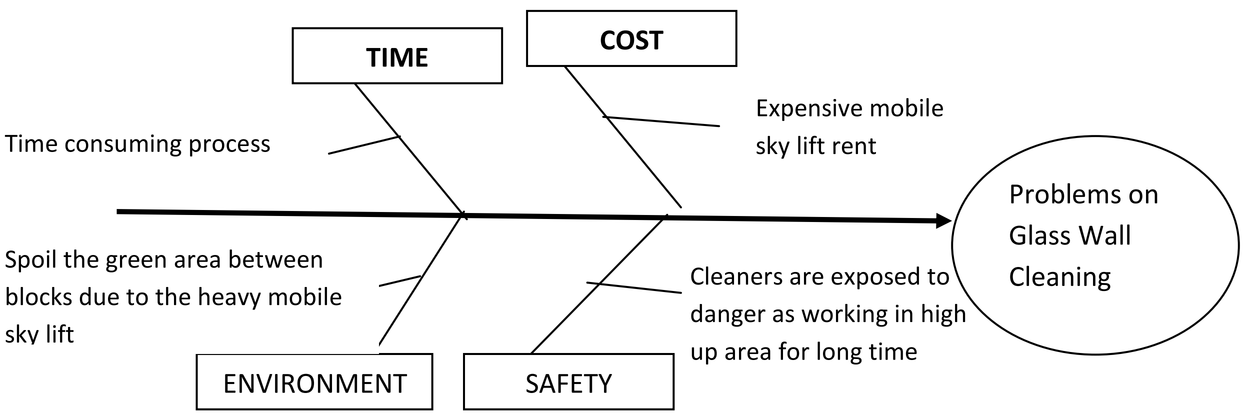


Figure 1.1: Fish bone diagram of the problems on glass wall cleaning

Figure 1.1 shows the summary of the problems face when cleaning the glass wall in UTP academic block. The problem arises when the glass wall on the outer side of the building from second to fourth floor required cleaning. The main problem with cleaning the glass wall panel is the cleaning cost. The cleaning job of the glass panel is sub-contracted to cleaning company, Liveline Sdn. Bhd. The price of cleaning the glass panel is fixed by contract between UTP and Liveline Sdn Bhd.

An interview session had been conducted with the technician in charge, Mr.Zuhali at the UTP Properties Management and Maintenance Department (PMMT) regarding the cleaning cost of the glass wall of each academic building. The outcomes of the interview are as follow:

- The glass wall cleaning work is not carry out by UTP PMMT instead, the job is sub contracted to the other cleaning company. In this case Liveline Sdn Bhd.
- The glass panels on the academic blocks are being clean twice a year. Each academic block requires minimum 2 weeks (10 working days) of cleaning time depending on weather condition.
- All the cleaners, sky lift and cleaning fluid are supplied by the sub contractor.

The table below shows the breakdown of cost of cleaning one academic block:

Table 1.1: Cost breakdown for cleaning an academic block

Descriptions/ Event	Cost (RM)
Sky lift	380.00 / day
Workers (8hr/day X 4 people) @ Rm5.60	180 / day
HSE officer x 1	80 / day
Cleaning Fluids / Equipment	200 / day
TOTAL = 840 / day	**10 working days= RM 8400 / block**

The other problems associated with cleaning the glass panel include:

- The cleaning process is time consuming. The time usually taken by the cleaning company to clean an academic block is minimum 10 days. If any of the day is raining, the cleaning process will be halt and continue when the rain stop.

- The mobile sky lift uses diesel powered engine to run. Therefore it will release high amount of carbon monoxide to the environment during cleaning process where the sky lift is needed to raise up and down to clean the academic block. This will pollute the environment while cleaning the glass panel

- Safety of the cleaning worker. Long hours of working from above ground could post treat or risk to the cleaner.

The significance of the project will benefit UTP management for being able to save money on maintaining the glass wall of academic building, the cleaner risk will be reduced because they no longer need to work high up and also will not pollute the environment because there is no exhaust fume from the mobile sky lift. The feasibility of the project is high as there is currently no other mechanism is commercially available for cleaning glass wall and the high cost of glass wall cleaning makes this project seem low cost enough to be research on.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objective of this project is to propose a detail design of a mechanism to clean glass walls with significant reduction in cost and time. The specific target is to reduce the cost not exceeding RM500 per cleaning session per building, to bring the cost of maintenance down at least by 50% and at least 50 % reduction of cleaning time from 2 weeks to 4 days. The main focus of this project will be the movement mechanism of the cleaning machine from one side of the building to other side of the building

The scope of this project is to design the mechanism that carries the cleaning approaches. The project will further discuss about the movement mechanism, and the cleaning mechanism. The subject that not covers by this project is how the whole mechanism overcome curvature surface because the target building is generally square and flat. The expected outcome of this project will be a vertical cleaning mechanism that cleans the glass wall panel of the wall of UTP academic buildings and able to move side wall with the support of a supporting system.

1.4 PRODUCT DESIGN SPECIFICATIONS

The glass wall cleaning mechanism need to be defined as detail as possible to achieve desirable result. Therefore, the criteria below have been drafted out to make sure that the focus of the project will not steer off the original plan. The table in the next page is the criteria for the project “to design the glass wall cleaning mechanism”:

Criteria	Current Situation	Improvement/ Target/ New Criteria
1. Performance	Glass panels cleaning takes 1 - 2 weeks per academic block	- To clean glass wall panel using top to down method. - To reduce glass panel cleaning time by at least 50 % ; 2 week to 4 days - Cleaning speed: to complete cleaning an academic block in 4 days time - The cleaning process is continuously from top of building to down.
2. Economy	High rental rate of mobile sky lift ; RM500/day	- To cut down the cost of cleaning glass panel to less than RM500/day - Production cost: RM 2000, one time off (support system + cleaning mechanism) - C Channel cost: RM 8000
3. Environment	Mobile sky lift produce exhaust gas polluting air	- To have NO pollution to the environment while glass wall cleaning
4. Size		- Estimated : 40 cm (length) X 40cm (width) X 15cm (high) - Small, Lightweight, easy to move around.
5. Weight		- Target weight: 30kg ; easy to handle
6. Maintenance		- Replaceable items: rubber blade and rotating brush (specially made) - Water source: direct from pipe - Total Maintenance cost: 10% of construction cost.
7. Quality and Reliability		- To have only 2 moving parts: electric motor for rotating brush and winch for supporting system - Less part= less reliability issue
8. Safety	Cleaner expose high from ground to work	- Mechanism is hold down by hoist using steel cable. - High tensile strength stainless steel cable with 0.5ton load is used.
9. Design time		• 1 year
10. Target Production Cost		• Production cost: RM 1000, one time off (for supporting sys + cleaning mechanism)
11. Competition		• Currently no competition in the market • There are 4 prototypes produced but not commercially available. •
12. Materials		• Stainless steel angle bar, rivets, rubber blade, steel nozzles and plastic brush

Table 1.2 Product design specification for Glass wall cleaning mechanism

CHAPTER 2

LITERATURE REVIEW

Four previous works in this area have been studied in order to be up-to-date with recent developments in glass-wall cleaning technology:

2.1 NON-ACTUTATED GLASS CURTAIN WALL CLEANING ROBOT.

The paper described a non-actuated glass curtain wall-cleaning robot prototype that was designed based on common traits of glass-curtain walls of high rise buildings. The robot does not have a drive mechanism but it can slide down through the glass curtain by using its own gravity and the lifting force of the trolley crane on the roof. While sliding up or down through the glass curtain, 2 suction cups help the prototype to stick to the wall for maximum cleaning efficiency. The journal also discusses about the method the robot move over obstacle such as window frame. From experiment the actual product does work in practice. Figure 2.1 show the real robot in action:

Figure 2.1: Non Actuated Glass Curtain Wall Cleaning Robot in action

2.2 “Sky Cleaner”- AUTOMATED GLASS WALL CLEANING ROBOT

Houxiang, Jianwei and Guanghua (2004, p.396) has previously designed a Glass-wall cleaning robot named Sky Cleaner. As quote from the article “Sky cleaner is totally actuated by pneumatic cylinders and attached to the glass wall with vacuum suckers” The reasons they use pneumatic system is that it offer cleanliness as well as low cost in operation. Air is available everywhere and require small amount of energy to compress air to operate the pump to move the Sky cleaner without worrying it will dirty the glass panel compare to hydraulic system which uses oil. The Sky Cleaner used 14 suction pads to support vehicle which is about 60 kg.

Based on the experiment, the Sky Cleaner manages to clean the Shanghai Science and Technology Museum. The Sky Cleaner manages to clean the 40 m above the ground and covered 5000 m². Below is the figure (figure 3) of the “Sky Cleaner” while cleaning the Shanghai Science and Technology Museum.

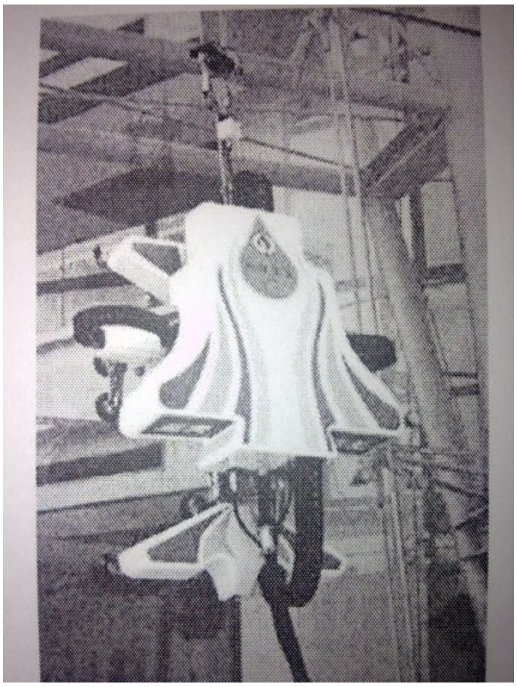


Figure 2.2: “Sky cleaner” glass-wall cleaning robot

2.3 " SURFY" A LOW COST AND LIGHT WEIGHT CLIMBING ROBOT

This journal discuss a new type of low cost climbing robot, name SURFY which is able to climb up vertical iron surface by means of 8 suction cups. The journal discuss the amount of the negative pressure is required to stick the robot on the wall and also the control of the air supply system to the suction cup. The robot suction system is able to lift up the robot 20 kg weight by just using 160 mbar vacuums. During experiments, the robot manage to suck onto all type of surface material such as painted wood and painted steel door without falling. This shows that vacuum does work on holding a heavy robot onto the wall. Figure 4 below is the robot SURFY

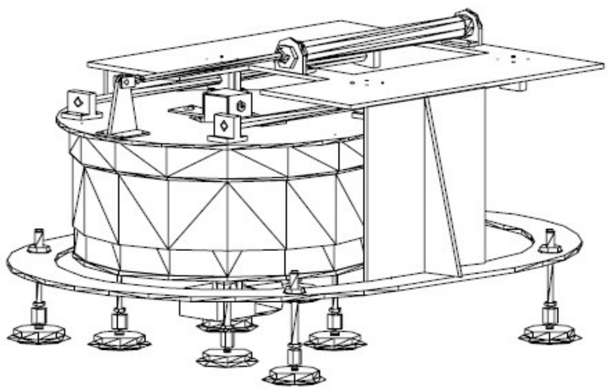


Figure 2.3: SURFY robot

2.4 VISUAL SENSING APPLICATION FOR GLASS WALL CLEANING ROBOT.

Dong Sun (2004) has designed a robot which can detect dirty spot on the window and move to the dirty spot to clean it by using visual sensor. The visual sensor system uses 2 laser diodes and a CCD camera to identify the dirty spot. Same as the above article, the cleaning robot designed by Dong Sun also uses pneumatic system to control the robot position on the wall. The 30 kg robot uses suction pad for adhesion at the glass wall. The robot move and rotate using the sticking-moving-sticking mode. This prove that pneumatic suction cups is capable and reliable to be use to adhere the mechanism on the glass-wall. Figure 5 shows the main frame of the robot and the position of the suction cups.

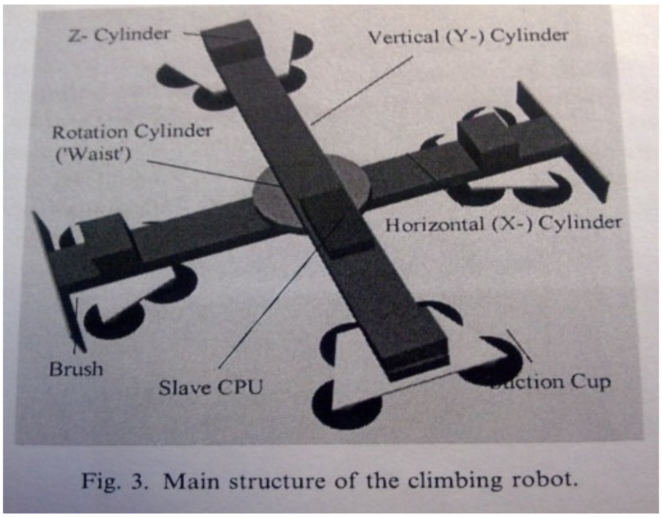


Figure 2.4: Main structure of the climbing robot and position of suction cups.

To move, the robot uses with a translation mechanism. The robot also has a flexible waist which all to adjust its orientation easily. The movement is control by the computer controlled by an operator. The robot can have a maximum speed of 3m/min and able to cross cracks and obstacles less than 35mm in height and 80 mm in width. To clean the glass-wall, 2 squeegees and sucking system is install on both side of the robot axis. The support vehicle connected to the robot feed cleaning fluid, the squeegee clean the dirt and the fluid is return to the support system via the suction system.

A summary of review of all the designs are presented in the table:

Table 2.1: Summary of All Literature Reviews

Name of Robots	Sky Cleaner	SURFY	Visual Sensing climbing cleaning Robot	Non actuated Glass wall cleaning robot
Drive/ movement Mechanism	Continuous sucking-extending-releasing of suction pads. Robot moves vertically down then horizontally one direction at a time.	Moveable in 2 axis at the same time with continuous sucking and releasing of suction pads on robot that control the movement direction	Moveable in 2 axis at the same time with continuous sucking and releasing of suction pads on robot that control the movement direction	Robot is lowered by a trolley crane with suction cup
Adhesive Mechanism	Pneumatic system -Total of 14 negative pressure suction pads	Pneumatic system- total of 8 suction cups to stick to wall	Pneumatic system – total of 12 suction cups	Pneumatic system enhance gripping of the robot to the glass wall
Cleaning Mechanism/ Function	Consist of water sprayer and 2 rubber wiper to clean glass panel	Multiple systems such as NDT, cleaning, Inspection can be mounted on SURFY	Using Camera and sensor to detect dirt and clean it. Using water spray and 2 squeegees to clean glass	Water spray with rotating cleaning roller and wiper to clean the glass panel
Advantages	Machine able to move independently	Robot can change direction while cleaning	Robot able to detect dirt n clean it by moving to it automatically	Simple and effective way to clean glass wall.
Disadvantages	Movement of suction pads too complicated	Movement of suction pads too complicated	Too many DOF make the robot very complicated	Robot unable to change cleaning path when done

CHAPTER 3

METHODOLOGY / PROJECT WORKS

3.1 PROJECT FLOW CHART

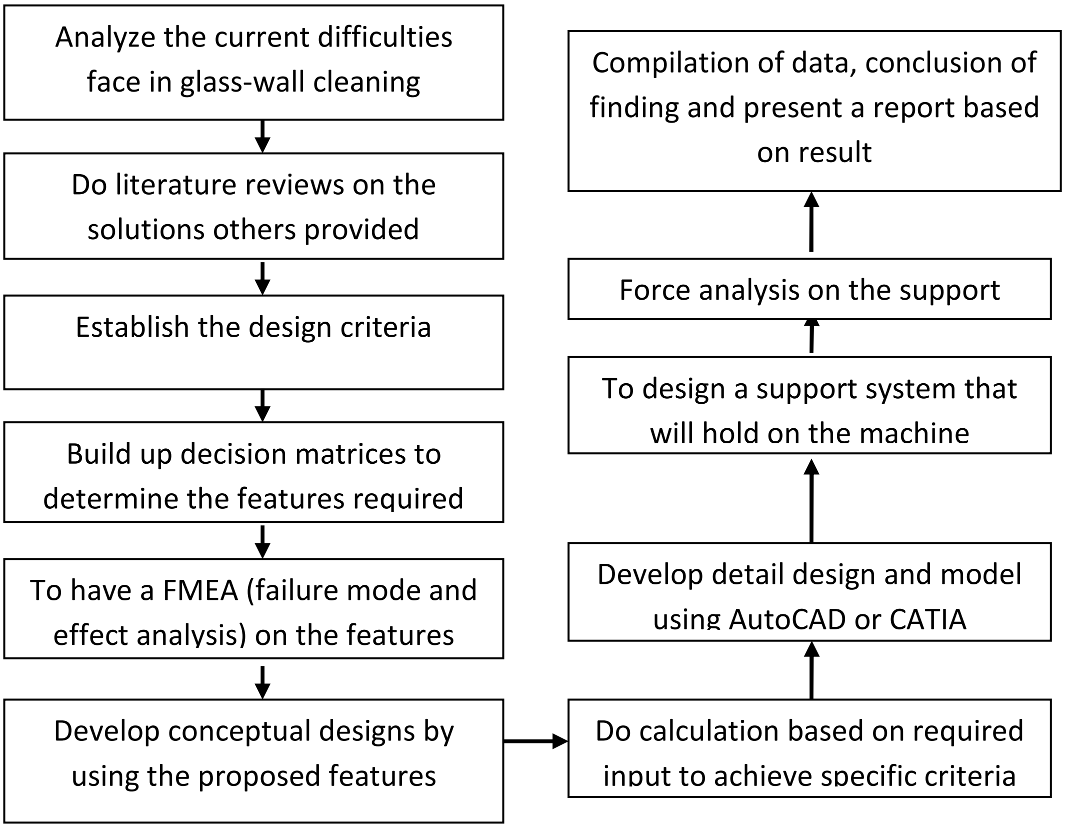


Figure 3.1: The process flow chart of the whole project

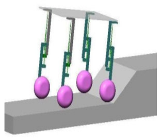
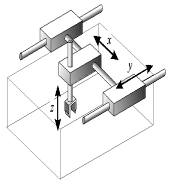
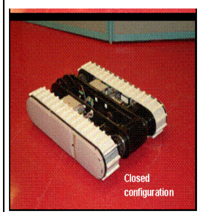
Figure above shows the project flow chart of this project. The project started with by identifying the problem statement to coming out with the design criteria up and finally come to the current progress which is to produce calculation based on the current criteria set. The Gantt chart which was in the appendix shows that time line of each progress and the time taken to finish up each specific task.

The Gantt chart of the project tasks can be referred in the appendix.

3.2 DECISION MATRICES

The decision matrix is used as a tool to determine the best option for a given need out of several possibilities. In the next step, there will be a series of decision matrices used to determine the best choice of components and mechanisms for the glass wall cleaning mechanism. The score 5 is awarded for the best fulfillment of the criteria and 0 for the worst. First of all, below is a table 3 of the available options for the mechanism and shall be narrow down using decision matrix:

Table 3.1: Option Matrix for Creating New Conceptual Design

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
Drive /Moving Mechanism	Walking (Legged) mechanism 	Wheeled mechanism 	Crawling mechanis m 	Translation Mechanism 	Track Mechanism 
Adhesive Mechanism/ Robot Positioning	Magnetic adhesion	Thrust force	Vacuum suction cup		
Cleaning Mechanism	Water Spray	Rotating brush	Wet Sponge	Rubber blade/wiper	
Power Source	Pneumatic System (compress air)	Electricity (electrical Motor)			

3.2.1 Drive / Moving Mechanism

Table 3.2: Decision Matrix for Drive/Moving Mechanism

Move Mechanism	Weight	Walking	Wheeled	Crawling	Translation	Track
D.O.F	2	1	4	1	5	4
Safety	5	2	4	2	5	3
Speed	4	1	5	1	4	4
Maintenance	3	1	3	1	3	4
Score	14	19	57	19	60	51

The score for the decision matrix is 0 for the worst and 5 for the best fulfillment of the criteria

To determine the drive/move mechanism, there are few factors that we need to consider.

- The degree of freedom must be relatively low than other moving mechanism. This to make sure that the complicity of the movement is minimum and less likely to breakdown. Machine with low D.O.F can move freely, faster and require less processing power.
- The less moving parts a mechanism has mean that the mechanism does not require expensive maintenance routine.

In this case, the translation movement mechanism is chosen because simply it has the lowest degree of freedom which is 1, and has the highest safety. However, it is slower compared to wheel and track but it will not affect much as speed was not a big concern in this case. The track and wheel require long track which make cleaning become more hassle as we need to install track on the glass wall.

3.2.2 Adhesive Mechanism

Table 3.3: Decision Matrix for Adhesive Mechanism

Adhesive Mech.	Weight	Magnetic	Thrust force	Vacuum
Usability	5	0	3	5
Reliability	3	5	2	4
Adhesiveness	4	0	3	3
Noise level	3	5	1	3
Score	15	30	36	58

The adhesive system, which job is to stick the cleaning mechanism to the glass wall plays a significant role to help the mechanism to achieve high cleaning efficiency. The vacuum system is selected because magnetic is useless in this case because glass is a non magnetic material while thrust force generate too much noise to be feasible to be used.

3.2.3 Cleaning Mechanism

Table 3.4: Decision Matrix for Cleaning Mechanism

Cleaning Mechanism	Weight	Water Spray	Rotating brush	Rubber blade/wiper	Wet Sponge
Cleanliness	5	3	2	1	3
Coverage Area	4	4	4	5	3
Reliability	3	4	4	3	3
Maintenance	3	5	4	4	3
Score	15	58	50	46	45

The result shows that water spray is the best cleaning method. However, it is decided to combine the best 3 selections to work together to achieve best cleaning efficiency.

3.2.4 Power Source

Table3.5: Decision Matrix for Power Source

Power source	Weight	Pneumatic	Electric
Reliability	5	3	5
adaptableness	3	3	5
Hazards	4	4	3
Score	12	40	52

The electric supply is selected to be the power source for the mechanism. Electrical power is chosen to power to electric motor which will raise/lower the mechanism and also to power to vacuum generator to make sure the mechanism attach to the glass wall.

3.3 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

The failure mode and effect analysis is commonly used as a tool to predict the failure modes of every single component in the design and to know the effect of it. This is to prevent any major breakdown of the design and to make sure the failure will not cause any major catastrophe damage to the user and surrounding. The table below shows the FMEA of the glass wall cleaning mechanism.

Table 3.6: FMEA for glass wall cleaning mechanism

Failure mode	Possible causes	Effects	Probability	Severity	Control Measures
Mechanism fail to move up/down on glass wall	Winch Jam	Mechanism hang on the glass plane	Low	Low	Service winch motor before deploy mechanism
	No electric current to motor				
Water jet fail to spray water	No water hose connected	Window unable to be clean	Medium	Low	Make sure that the water hose is connected properly.
	Spray nozzle clogged				Clean nozzle after every use.
Steel cable snaps	Steel cable overload	Mechanism might fall down	Low	High	Have a safety factor on steel cable load

3.4 PROCESS WORKFLOW

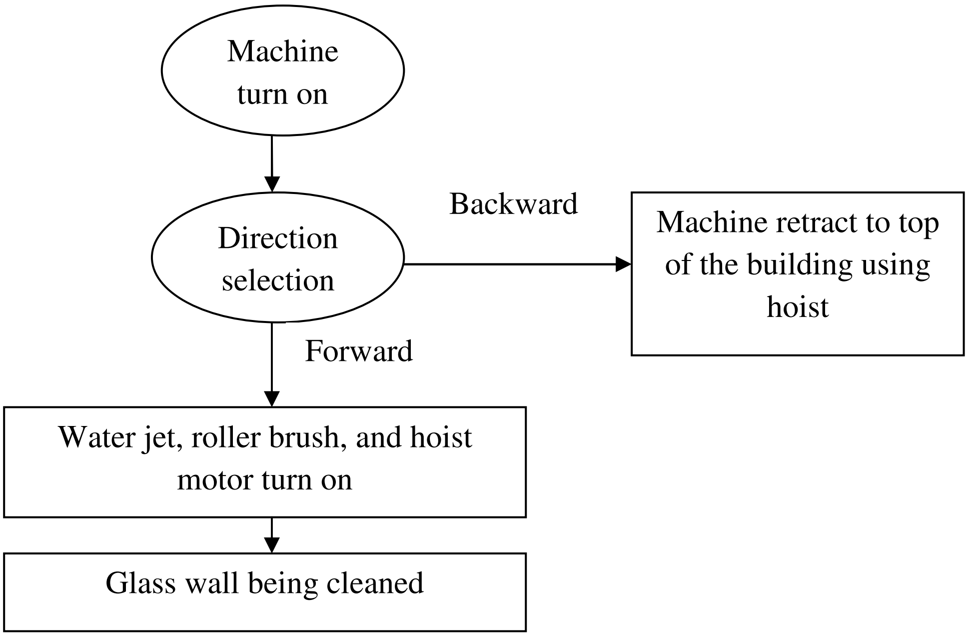


Figure 3.2: The flow chart of the glass wall cleaning mechanism in work.

The figure above shows the flow chart of the glass wall cleaning mechanism in action. When the power button is turn on, and the forward button is selected, the machine will move from the top of the building to toward the down direction. In the mean time, all the other processes such as water jet and roller brush will turn on in order to clean the glass.

However, when the backward button is selected, all the other functions will not be on instead the machine will move from the bottom toward the up direction to back to its original direction. When it is back to its original direction, the machine can be relocated to another glass plane.

3.5 CONCEPTUAL DESIGN BASED ON SELECTED CRITERIA

2 conceptual design have been come out with and they need to be analyzed with great detail to find out it advantages and disadvantages before decide which conceptual design is the most suitable design to be carry on as our project detail design.

3.5.1 Conceptual Design A

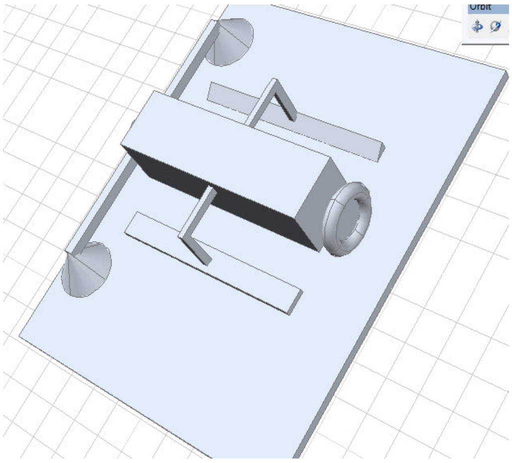


Figure 3.3: Conceptual Design A

Figure 3.3 above show conceptual design A, the design is based on the options matrix. The conceptual design is not drawn up to scale and only for reference of it shape and functions. More pictures are put under appendix for better view of the conceptual design A. Below is the summery of this conceptual design.

- Drive mechanism: Translation Mechanism.

The robot is connected to a pinion gear and the pinion gear is coupled with another gear into a rack gear/track to allow it to move up and down along the glass panel. The rack gear is mounted on 2 vacuum suction cups that can be remove and attach manually to change the robot direction. A guide wheel is installed on the right side of the robot functioning as a guide wheel.

- Adhesive mechanism: Vacuum Suction Cups.

The whole robot is attached to the wall by vacuum suction cup that are combine with the rack gear. Initial concept suggested 2 suction cups are needed.

- Cleaning mechanism: wet sponge + rotating brush roller + rubber wiper

Combination of wet sponge in the front of the robot, rotating brush roller in the centre and a rubber blade at the end of robot for cleaning the glass panel.

- Power Source: Electrical

Pneumatic system is for the suction cup and electricity is for the movement of the pinion gear. The machine will be manual operated by operator to change its direction and course.

Verdict: A simple mechanism to clean the glass panels. The design does not contain too many moving part which means higher reliability and maintainability. Track mechanism ensure that the robot travel in a straight path without the assistant electrical components. However, the machine needs to be move manually to switch to different path so that cleaning can continue.

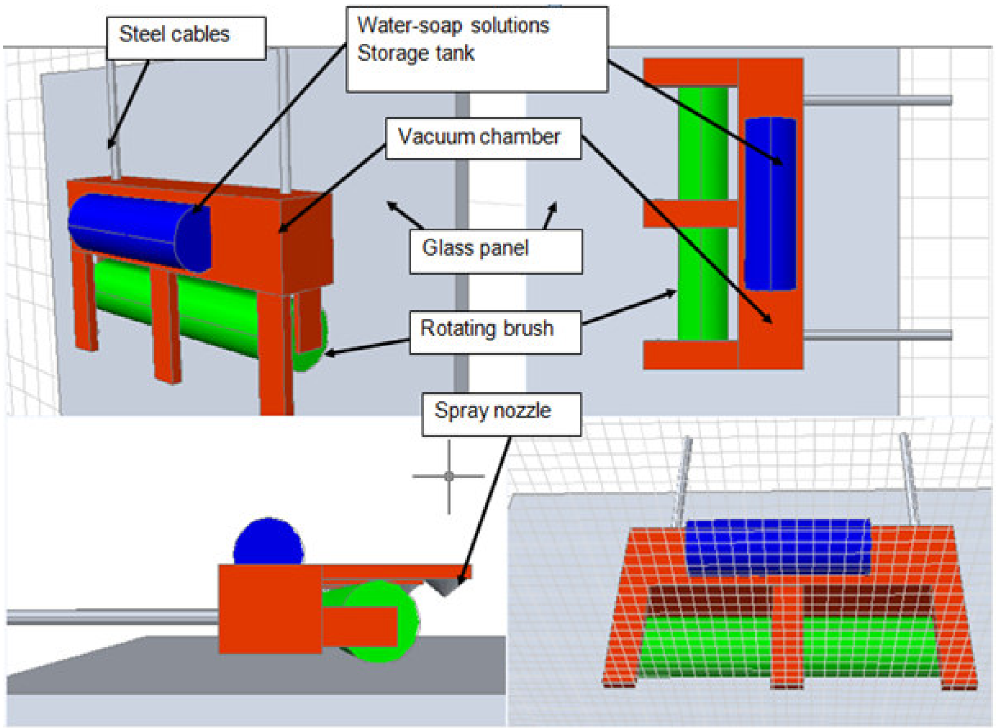


Figure 3.4: Conceptual Design A in various views

3.5.2 Conceptual Design B

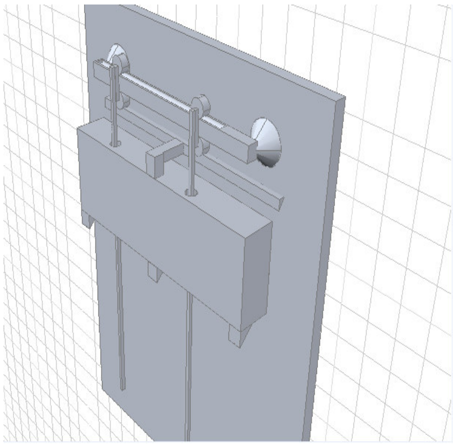


Figure 3.5: Conceptual Design B

Figure 3.5 shows conceptual design B, the design is based on the options matrix. The conceptual design is not up to scale and only for reference of it shape and functions. . Below is the summery of this conceptual design:

- Drive mechanism: Wheel Mechanism

The robot is mounted on 2 set of double rollers. There is one for horizontal movement and another for vertical movement. Rollers enable fast moving for robot and less friction compare with gears. Besides, roller can provide better accuracy in term of moving position.

- Adhesive mechanism: Vacuum Suction Cups.

The whole robot is attached to the wall by vacuum suction cup that are mounted on the railing which the rollers sit on.

- Cleaning mechanism: water spray nozzle + non-rating brush + rubber wiper

Water spray nozzles, non-rotating brush and rubber blade wiper are used to clean the glass panels. The robot will be connected with a water hose to continuously supply water to the water nozzle.

- Power Source: <u>Electric</u>

Electrical motors will be installed to move the rollers so that it can drive the mechanism around the glass wall.

<u>Verdict:</u> The rollers concept for drive mechanism seem a fast way to move the mechanism around a glass wall but there is too many rollers and electrical motors needed to be involved to move the mechanism. This will lower the machine reliability as more parts are involved. In addition, the system requires a long track for the mechanism to travel. Besides that, the water spray nozzle need continuous supply of water to work which eventually waste a lot of water to clean the glass.

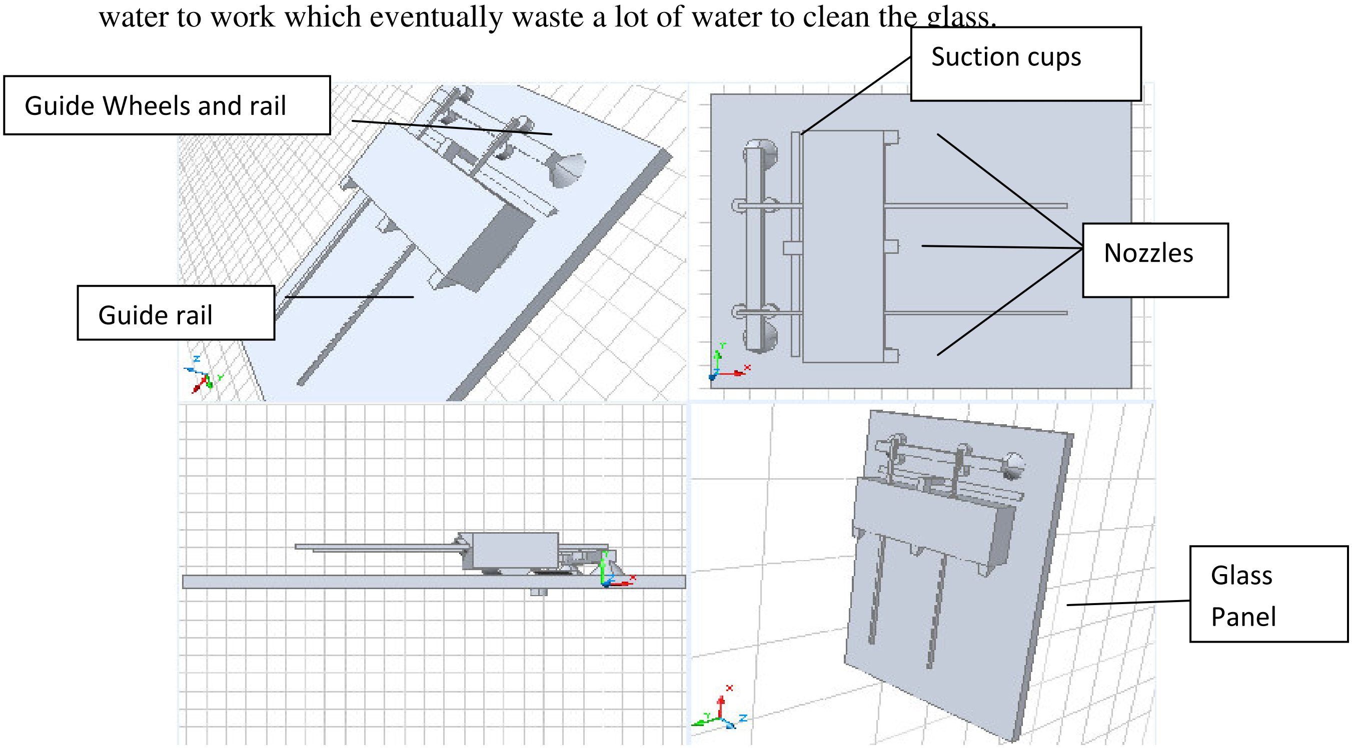


Figure 3.6: Conceptual Design B in various angles

3.6 CONCEPTUAL DESIGN SELECTION

After considering all the conceptual designs, conceptual design A was chosen based on its simplicity and ease of functionality. The selection was done with the aid of the decision matrix shown in table 3.7 However, design A will be subjected to a number of modifications that will be discussed in the next chapter.

Table 3.7: Decision Matrix to justify the conceptual design

Conceptual design	Weight	Design A	Design B
Usability	5	3	3
Maintenance	3	4	3
Simplicity	3	3	4
Ease of installation	4	4	2
Score	15	52	44

CHAPTER 4

RESULT AND DISCUSSION

4.1 DETAIL DESIGN OF THE GLASS WALL CLEANING MECHANISM

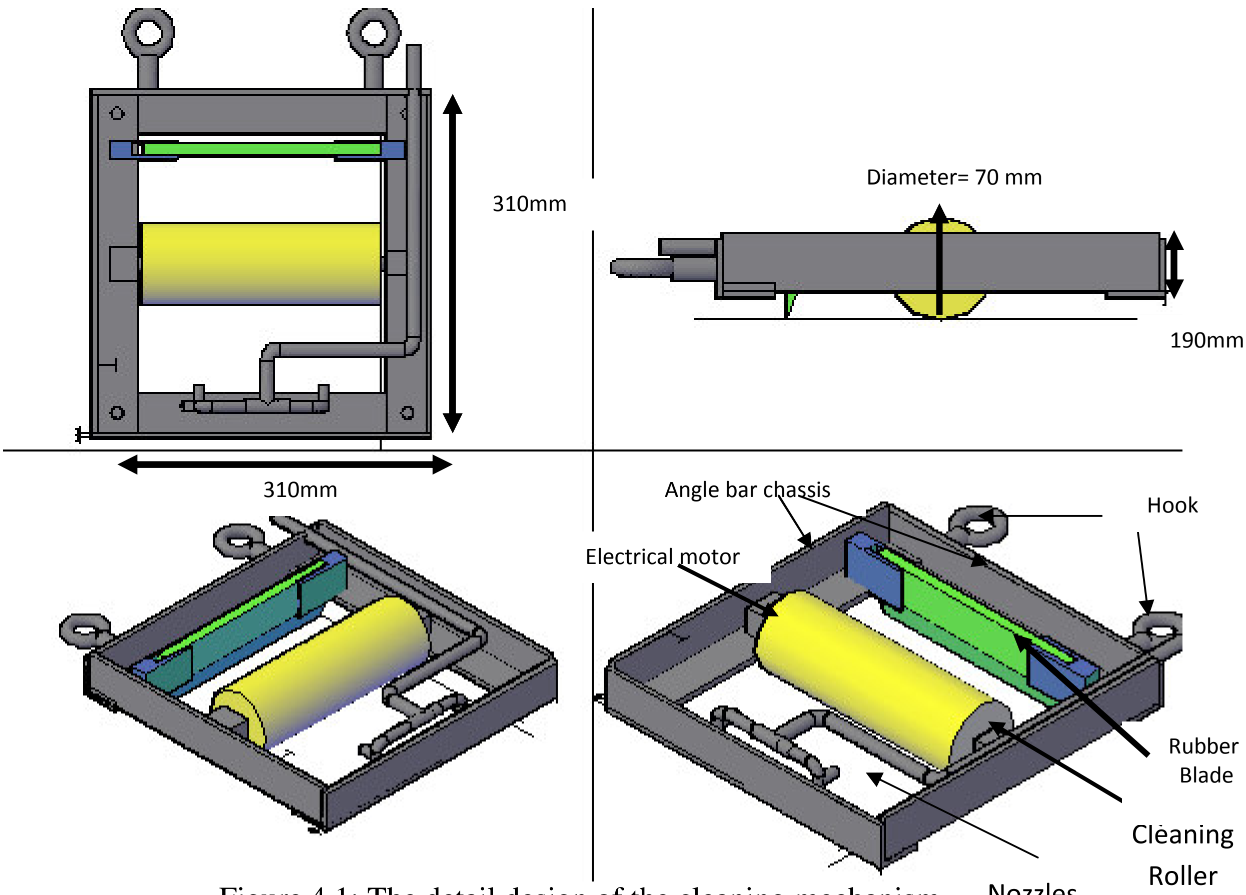


Figure 4.1: The detail design of the cleaning mechanism

The above detail design of the glass panel cleaning machine is drawn based of the conceptual design A. The details of the design are as follow:

Table 4.1: Criteria of the design cleaning mechanism

Criteria	**Value**
Length	310 mm
Width	310 mm
Height	190 mm
Weight	20 kg
Cleaning Roller diameter	70 mm
Rubber blade length	210 mm

The detail design is designed to meet the product specification requirement set earlier. The length and the width are subjected to 31 cm because this allows the cleaning mechanism to be move around easily when it is not in use. The Weight is calculated based on the angle bar specification sheet, and some assumptions. The 20 kg weight is acceptable because it would not need a large support system to support it while under cleaning operation. The roller brush diameter is set to be 70 mm so that it could have a good surface contact with the glass wall panel.

4.2 SUPPORTING SYSTEM FOR THE CLEANING MECHANISM

The cleaning mechanism will not able to support itself due to lack of adhesive system. The reason being why the vacuum adhesive system is being left out although it is being justified is that vacuum adhesive system tends to have problem with suction leakages and will not able to perform under wet condition. To replace the adhesive system, a supporting system which is also part of the translation mechanism is design to hold and support the cleaning mechanism and also to move around the building will cleaning

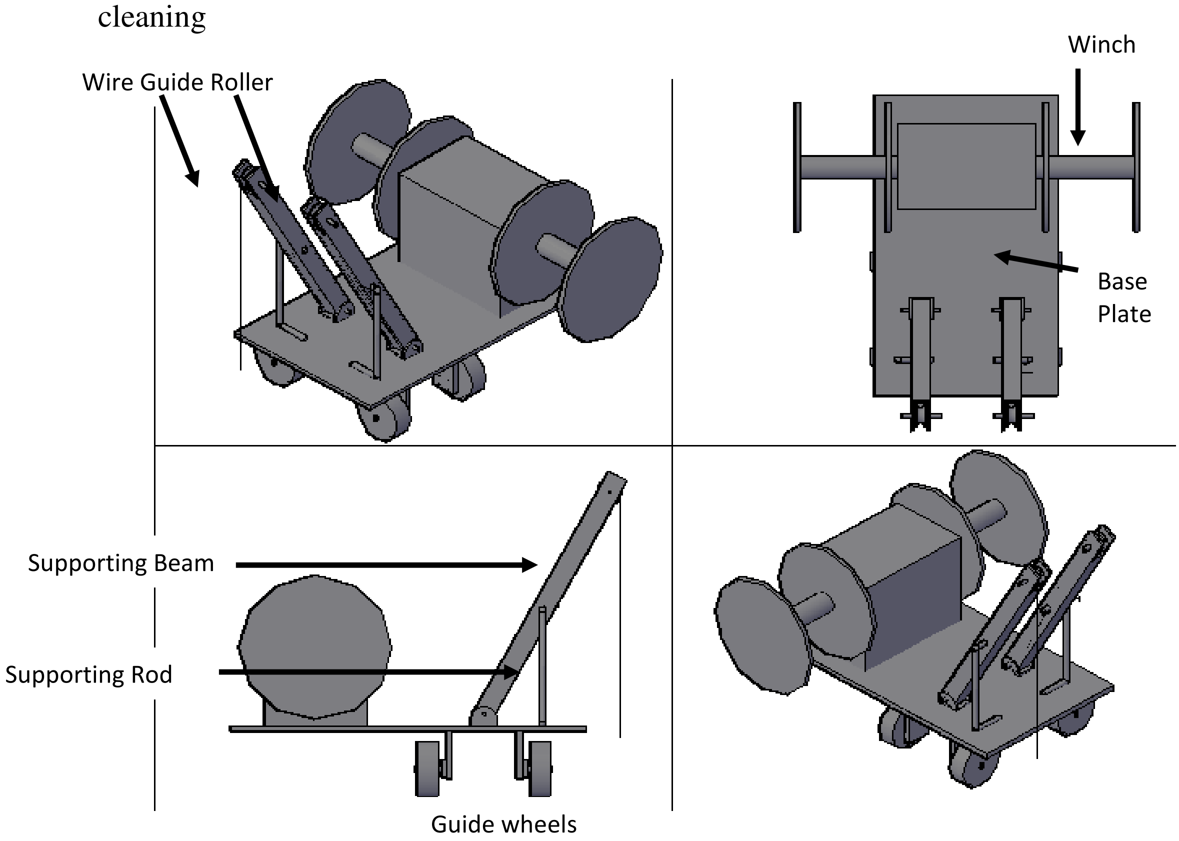


Figure 4.2: The support system (translation mechanism)

The support system is made up of a winch to hoist the cleaning mechanism, steel cables, and 2 incline metal bar with mounted pulleys to adjust the angle and wheels to move around the track across the building.

The support system will be mounted on C channel on the edge of the building. This feature enables the cleaning mechanism to be move across the building easily. Besides using the supporting system for supporting the cleaning mechanism, the supporting system can be used to hang up banners and so forth.

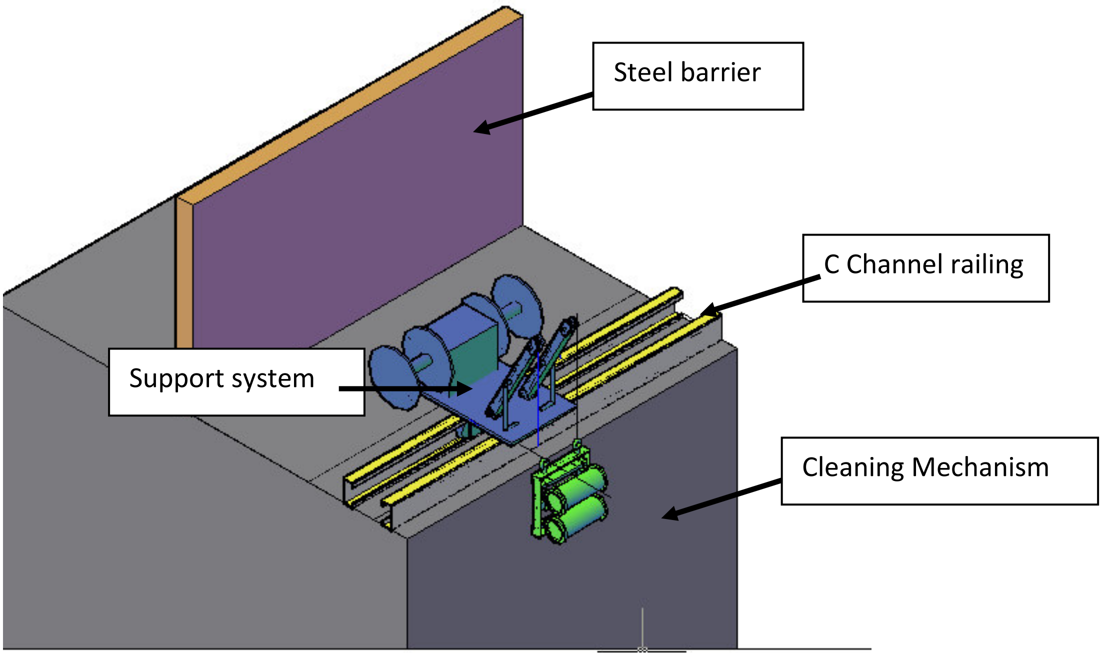


Figure 4.3: Example of supporting system with the cleaning mechanism on an academic block

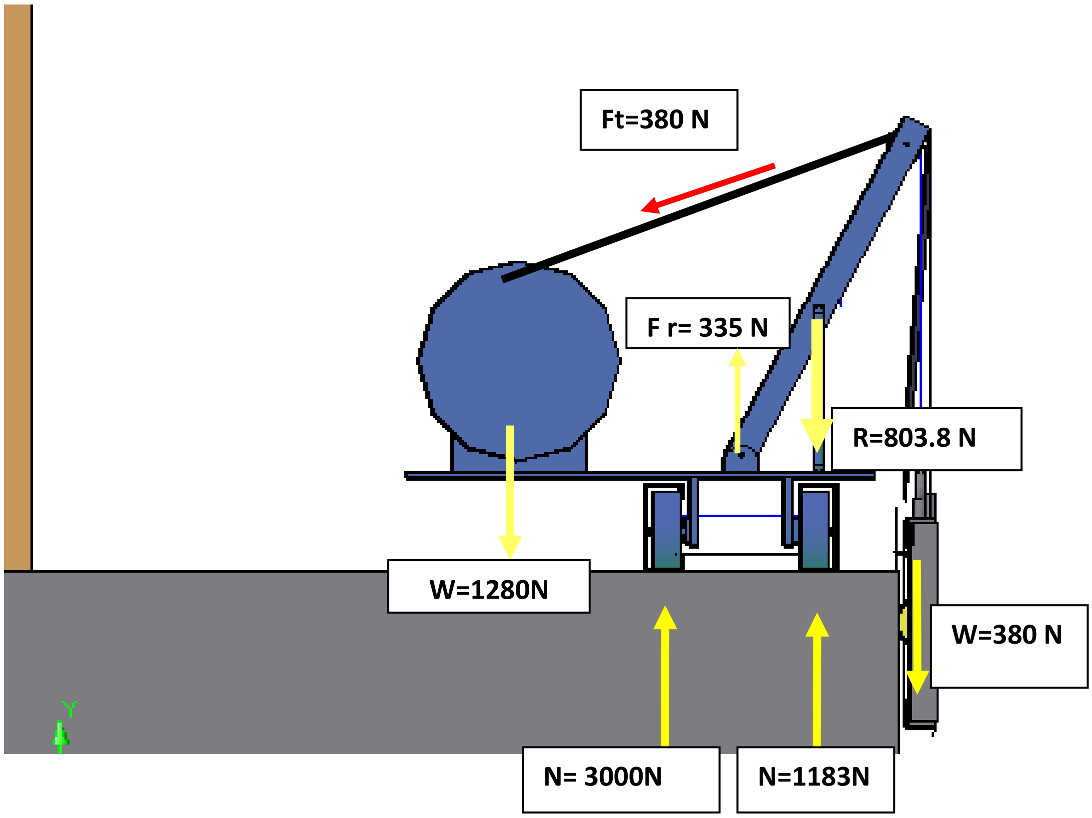
Estimate total cost for this project:

Table 4.2: Total Construction cost of the cleaning mechanism and the supportive system

Description	Price
C channel	RM 8000 (one time off)
Supporting system	RM500 (one time off) X 2
Cleaning mechanism	RM 500 (one time off) X 2
Total	RM 10000 construction fee/ academic block

4.3 FORCE ANALYSIS ON SUPPORT SYSTEM

Figure 4.4: Force analysis on the Supportive system with the cleaning mechanism



The figure above shows that the force distributed around the support system which have to sustain the cleaning mechanism. The estimated weight of the cleaning mechanism is around 380 N. the weight of the cleaning mechanism is supported by the square beam and the 0.5 ton stainless steel wire. The supportive wheel plays a large role here to be able to support the whole system. The force the wheels need to sustain is about 3000N. Therefore the C Channel guide track must be welded on the side on the building.

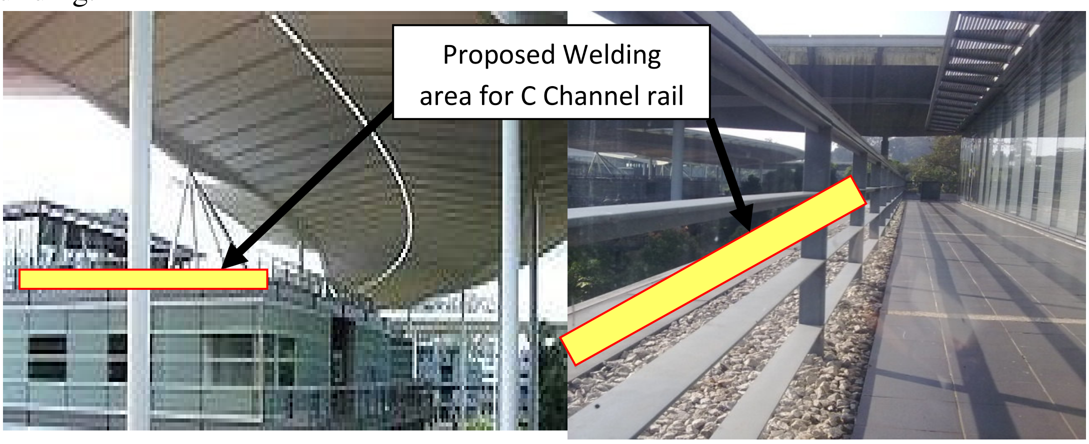


Figure 4.5: Propose site for C Channel installation

4.4 COST COMPARISON BETWEEN EXISTING CLEANING OPERATION PROPOSED AND CLEANING MECHANISM OPERATION.

The main purpose of this project is to lower the maintenance cost of the glass wall panel on the academic. Therefore, it is important to see the costs of the production and installation of the cleaning mechanism the running cost of the proposed mechanism in detail. Apart from that we, should also compare the cost of operating the cleaning mechanism versus the cost of paying the contracted cleaning company to clean the glass panel. Below is the analysis of both methods:

Table 4.3: Cost comparison between contractor cleaning and cleaning mechanism

Year	Cost Comparison	
	Contractor Service	Cleaning mechanism.(Estimated cost)
1	RM 8400/academic block Total Maintenance cost /year =RM8400 X 14 Block = RM117600 /yr Price here shown is the minimum cost charged by the contractor.	Cost of installation of C Channel =RM 8000 Cost of Production of cleaning mechanism + Support system =RM1000 X 2 side/building=RM2000 Total Production cost =RM 10000/academic block X 14 Blocks =RM 140000 Total Running and Maintenance Cost = RM10000 X 5% = RM 500/block/year = RM 7000/year for 14 blocks
2	RM 117600/year	RM7000/year
	Total saving in second year = RM 117600 – RM 7000 = RM 110600	

From the comparison table above, the cost of maintenance drops from RM 117,600 per year (contractor cleaning) to just RM 7000 per year (cleaning mechanism) second year onwards. This in return should help the university management to save about RM 110600 in the second year. Although the cost of production and installation is slightly higher in the first year, this will be compensated by the saving that can be obtained if the cleaning mechanism and support system is used. The electricity and water being used is estimated to be within the 5% running cost.

4.5 THE BILL OF MATERIAL FOR THE SYSTEM

Table 4.4: The Bill of Material for both Cleaning Mechanism and Support System

Cleaning Mechnaism			
No.	Item	Quantity	Cost
1	Angle bar 90', ASTM A276, 5mm(T) X 30mm(H) X 30mm(W) X 300mm(L), 1.8kg/m	4	est. Rm10
2	metal hose; OD 8 mm	2m	est RM 75
3	nozzle; OD 8mm	2	est RM20
4	T splitter; OD 8mm	1	est RM 22
5	Rivets; 10MM(D) x 7MM(H)	4	est RM 10
6	Small Electric Ac motor for cleaning roller	1	est RM 50
7	Cleaning Brush Roller; 210mm(L) X 70mm (D)	1	est RM40
8	Rubber blade; 210mm	1	est RM 20
9	Hook; Torus radius 17.5 mm, tube radius 5 mm	2	est RM 10
10	Holder for Rubber blade	2	est RM 10
Support Sytem			
No.	Item	Quantity	Cost
1	Metal Plate	1	est RM50
2	Electric Winch 0.5Ton load	1	est RM 500
3	Roller	2	est RM50
4	Square Beam	2	est rm 100
5	Pivot	2	
6	Metal Supporting Rod	2	
7	Metal wire	9 meter	est rm300
8	Wheel	4	est rm50
9	Wheel Support	4	est rm50
10	C Channel	2 X 66 m	est rm8000

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The table above show the parts and items needed to be assembled together the cleaning mechanism and the support system. The total assembly cost of the cleaning mechanism is RM 267.00 while the cost of assembling the support system cost RM 700.00. The total cost of the installation and construction of the whole system cost RM 10000 per block. This consist of 2 C Channel guide, 2 supportive system and 2 cleaning mechanism which will be installed on both side walls of the academic block.

The items that need to be replaced frequently for the cleaning mechanism are the rubber blade which cost RM 20 and the cleaning brush roller which cost RM 40. The costs would also be included into the 5% running cost as mentioned earlier in the cost comparison. The frequency of changing the cleaning roller and rubber blade is scheduled at each cleaning services.

4.6 **COST ANALYSIS BETWEEN EXISTING CLEANING OPERATION PROPOSED AND CLEANING MECHANISM OPERATION**

The cost analysis of both options of Contractor Service and Mechanism Installation has to be carried out to figure out which of the options is feasible and cost saving to be carried out. The first analysis will be using the annual worth method. For the cost analysis section, we are looking the cost as in per academic block, we also going to target 5 years as the operation year and the Minimum Attractive Rate of Return, MARR set at 15%. Besides, we assume that there is no Salvage value of both options.

Contractor service

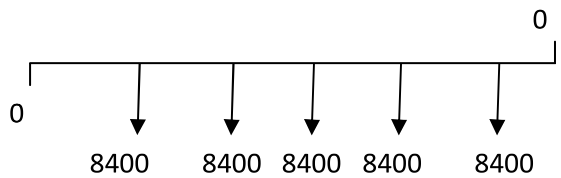


Figure 4.6: The Cash Flow diagram for contractor service

The Annual Worth = RM 0(A/P, 15%, 5) + (- RM 8400)

= - RM 8400/year /block

Cleaning Mechanism

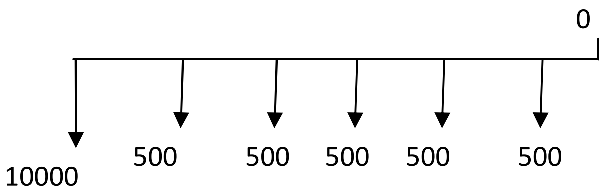


Figure 4.7: The Cash Flow Diagram for Cleaning Mechanism

The Annual Worth = RM -10000(A/P, 15%, 5) + (RM -500)

= RM -10000(0.29832) – RM 500

= RM -3482/year/block

	Contractor Service	Cleaning Mechanism
Present Worth, PW	RM – 28158.00	RM -11676.10
Annual Worth, AW	RM – 8400/year	RM – 3482/year
Future Worth, FW	RM – 56636.16	RM – 23485.2

Table 4.5: The Present, Annual Future Worth of the both options

From the cost analysis, we can see that the installation and operate of the cleaning mechanism is cheaper than the contractor service. This justifies the purpose of this project which is to safe the cost of maintenance of the glass wall panel of the academic block. Therefore, the project should save UTP management money in term of using the cleaning mechanism for a long time.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In the beginning of project, we have identified cost is one of the major issue that strike UTP management when come to glass wall panel cleaning on the academic block. This is because the cleaning contractor charge a fix price based on the contract sign between UTP and the cleaning company. Besides that, the cleaning company usually takes about 2 weeks just to clean only one academic block. Therefore, this project "Design a glass wall cleaning mechanism" has set it purposes and objectives which are to design a glass wall cleaning mechanism which can cut down the cost of cleaning at least 50% and to reduce the cleaning time from 2 week to minimum 4 days per academic block.

We started off the project by defining the criteria needed to have in a glass wall cleaning mechanism. So far the best criteria that we have determined using decision matrix is to have in a cleaning mechanism is to have a translation movement mechanism, water jet spray to clean the glass wall, having a vacuum suction mechanism to stick to the wall and it will be running on electricity. We had come out with the concept design based on those criteria and we manage to work on one of the conceptual design to be the detail design.

Throughout the whole project, we have design the detail design of the cleaning mechanism and also the supporting system, analyzed the force exert by the system, the breakdown of the bill of material and also the cost analysis of the system compare to the operator service. This is to make sure that the design that we have come out with match with the criteria and objectives we set before we start the project.

Overall, we have try to design a glass wall cleaning mechanism that presumably has achieve that objectives set which is to reduce cleaning cost, reduce cleaning time and eliminate environment pollution while cleaning the glass wall panel based on our assumption and estimation.

5.2 **RECOMMNADATIONS**

Even though the project has achieve its goals and objectives, it still have some room for improvement that can be worked on so that a better product or result can be achieve by other designer.

Among the future works or improvement suggestions that can be added into this project are:

- To improve the cleaning mechanism. The current cleaning mechanism is just a basic cleaning tool that is combined together to clean the glass panel. The suggestion is to add enhance cleaning technique into the mechanism such as anti fungal protection to the glass panel as it cleans or the polish the glass panel using waxing agent.

- Reduce the weight of the mechanism and the supportive system. This improvement will allow the machine to be easier to carry around so that we do not need to have 2 supportive systems per academic block as one will be sufficient if it is light enough to be carry around.

- Increase the cleaning area using the machine. The current cleaning mechanism clean only 0.09m^2 at each time. It is advice to build the machine larger and wider to have more cleaning area per time.

These are the recommendation work that can add into the current project to enhance the project even further.

References

1. Guido La Rosa, Michele Messina, Giovanni Muscato, R.Sinatra, 5 April 2000 “A Low Cost Lightweight Climbing Robot for The Inspection of Vertical Surfaces”, Science Direct: Mechatronic 12(2002) 71-96

2. Zhi-Yuan Qian, Yan-Zheng Zhao, Zhuang Fu, Qi-Xin Ca, 2006, “Design and Realization of a non –actuated glass-curatin wall-cleaning robot prototype with dual suction cups”, international journal of Advance Manufacturing Technology 2006, 147-155.

3. Houxiang Zhang, Jianwei Zhang and Guanghua Zong, 2004, “Realization of a Service Climbing Robot for Glass-wall Cleaning.”, International Conference on Robotics and Biomimetics: 395-400

4. Dong Sun, Jian Zhu, Chiming Lai and S.K. Tso, 2004, “A Visual Sensing Application to a Climbing Robot on the Glass Surface”, Science Direct, Mechatronics 14(2004) 1089-1104

5. Bing L. Luk, David S. Cooke, Stuart Galt, Arthur A. Collie, and Sheng Chen, 2005, “Intelligent legged Climbing Service Robot for Remote Maintenance Applications in Hazardous Environments”, Science Direct, Robotics and Autonomous Systems 53 (2005) 142-152.

6. Intelligent Robotics & Mechatronics System Laboratory School of Mechanical Engineering, Sungkyunkwan University. 2007, http://mecha.skku.ac.kr/board/list.php?bbs_id=Robotics_02

7. C-Bot, wall climbing a cinch, Niklas Galler, 2008. http://www.yankodesign.com/2008/03/05/wall-climbing-a-cinch/

8. The Star.com.my Lorry, crane operators up rates by as much 45%, June 2008 http://thestar.com.my/news/story.asp?file=/2008/6/8/nation/21491811&sec=nation

Appendix

1. Gantt's chart for the project:

Semester 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Topic allocation										Mid-semester break					
2	Analyze current problems in glass-wall cleaning activities															
3	Do Literature review on research and prototype of glass-wall cleaning mechanism															
4	Establish design criteria															
5	Mechanisms for machine are being studied and determined based on the decision matrix															
6	Failure Mode and Effect Analaysis															
7	Develop conceptual design															
8	Future works allocation															

Semester 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Work on progress: Detail design of the glass panel cleaning machine										Mid-semester break					
2	Work on progress: To design he support system for the machine															
3	To calculate the specification of the detail design and support system															
4	Supportive system force analysed															
5	Cost comparison															
6	Bill of material of system															
7	Compilation of data, finding and design															

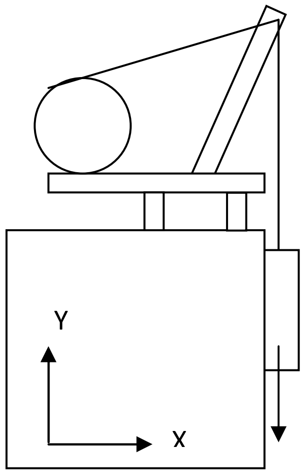
Appendix

2. Criteria selected based on engineering calculations

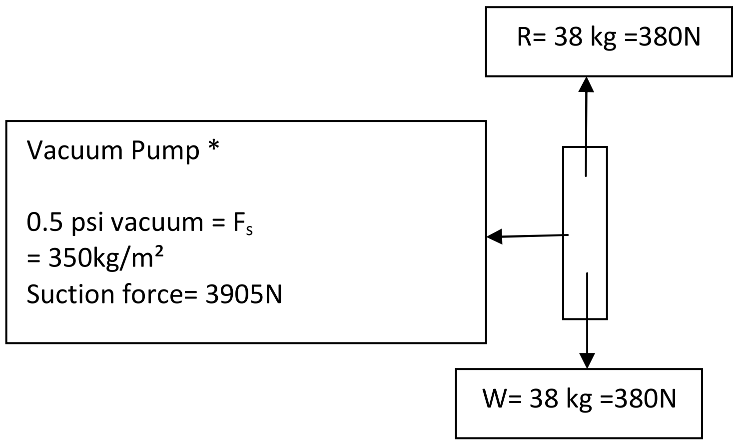
Moving Mechanism

Criteria selected	Basic calculation
Translation Mechanism	Total Height of building for 1st and 2nd floor: 7.2meter Winching speed max, from catalog: 39 RPM with Θ165 m = 22m/min Speed needed = 0.3m/min to have an effective cleaning by the roller. Possibilities of controlling the speed of winch using a speed controller. Time need, t=D/v = 7.2meter ÷ 0.3meter/min = 25.3min per vertical row. -- Area of the cleaning mechanism per vertical row= 0.3m X 7.2m =2.16m² Total glass area of 2nd floor and 3rd floor = 1003.2m² Cleaning count: 1003.2m²/2.16m²= 464 times Total time= 464 times X 25.3 min per vertical row =11748 min =195 hours = 8 days Conclusion : The speed is acceptable compare to contractor service

Adhesive Mechanism

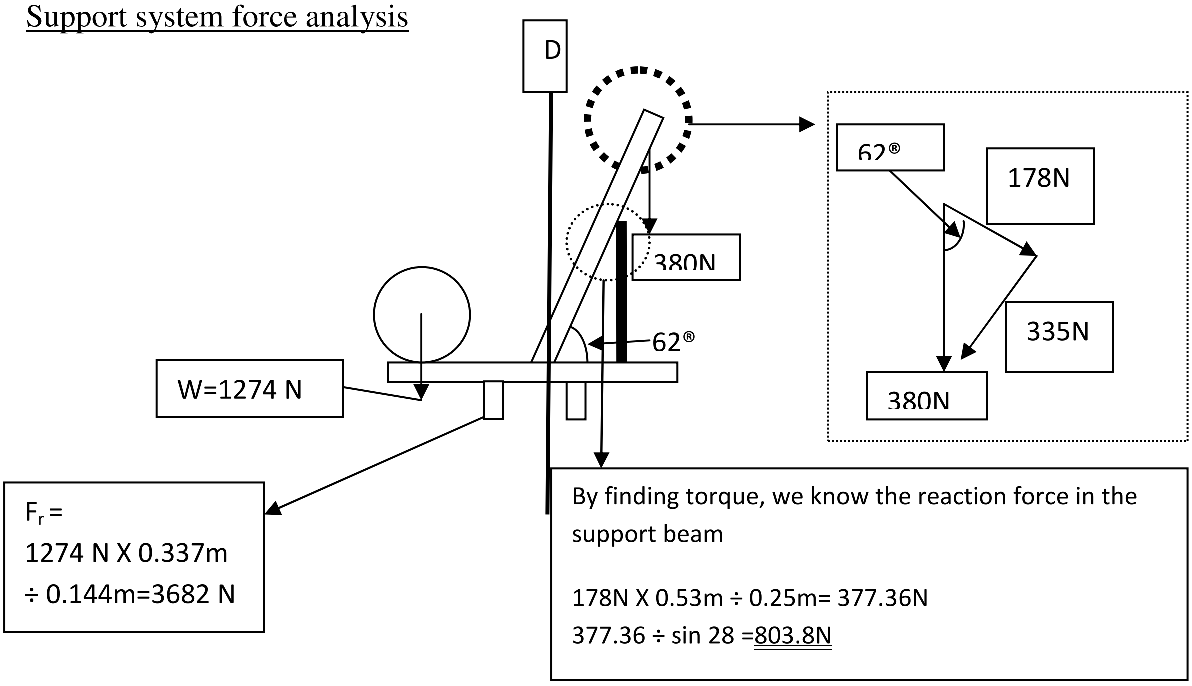


Cleaning mechanism force analysis



*Recommended work: Current design not having vacuum pump installed, recommended to install onto cleaning mechanism for full contact with glass panel.

Support system force analysis



Cleaning mechanism

a) Water usage

Water nozzle size and hose size = 8 mm

Area of the hose, A= $A = \pi r^2 = 3.142 * 0.008^2 = 2.01088e^{-4}m^2$

Assume water tap velocity, V is 1.0m/s

Flow rate, Q = Av = $2.01088e^{-4}$ X 1= 2.01m^3/s= 0.012m^3/min

Total water usage per academic block for cleaning the glass wall

= 0.012m^3/min X 11748 min

Water usage = 141.74m^3

b) Electricity usage

Roller brush size = 70mm in diameter

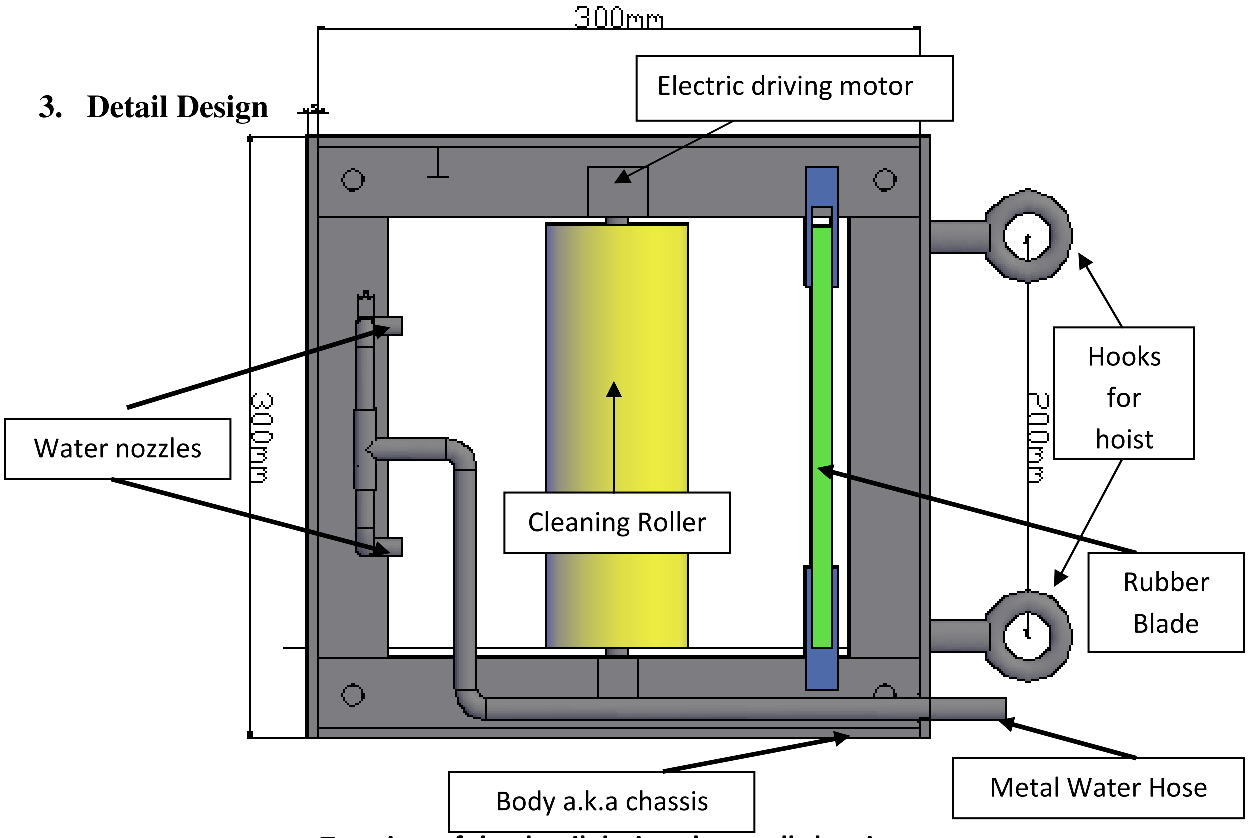
Motor selection,

Voltage	7.2 V
Current	1.7 Amp
Torque	4.4kg/m
RPM	Adjust to 1000 RPM

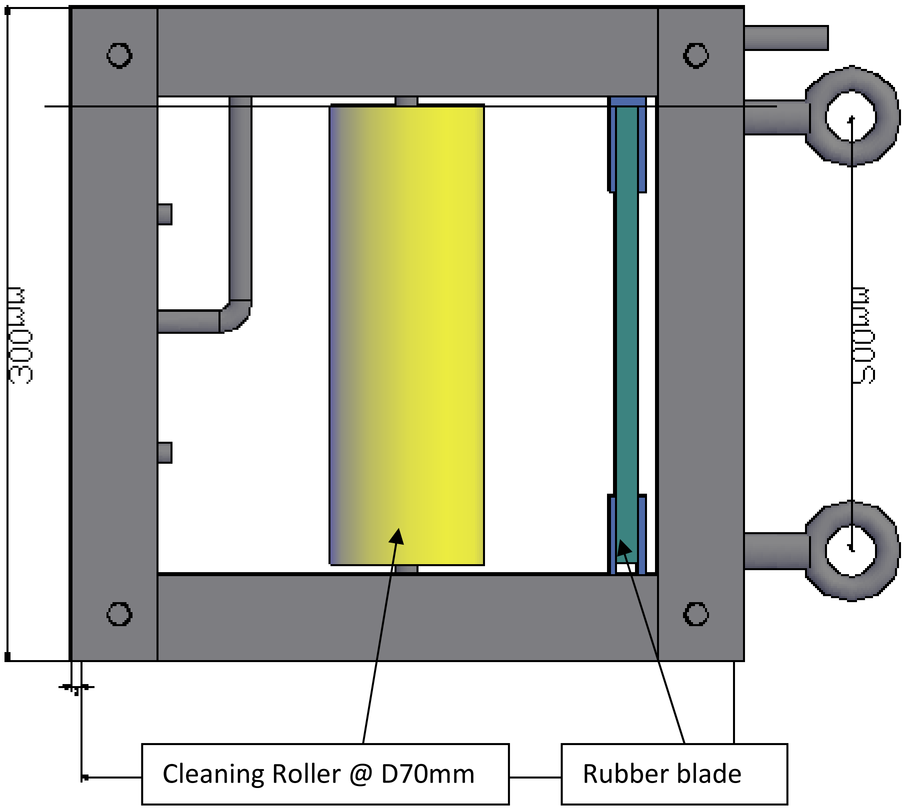
Power, P= VI, 7.2 V X 1.7 Ampere = 12.24 watt

Total Energy used for cleaning one building = 12.24 watt * 8 days = 8294kJ

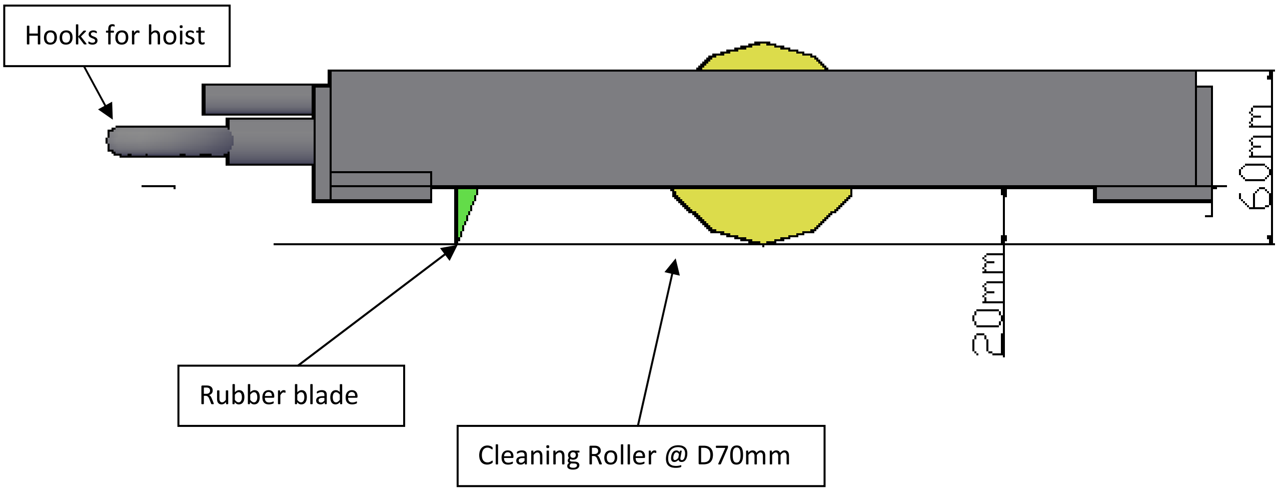
3. Detail Design



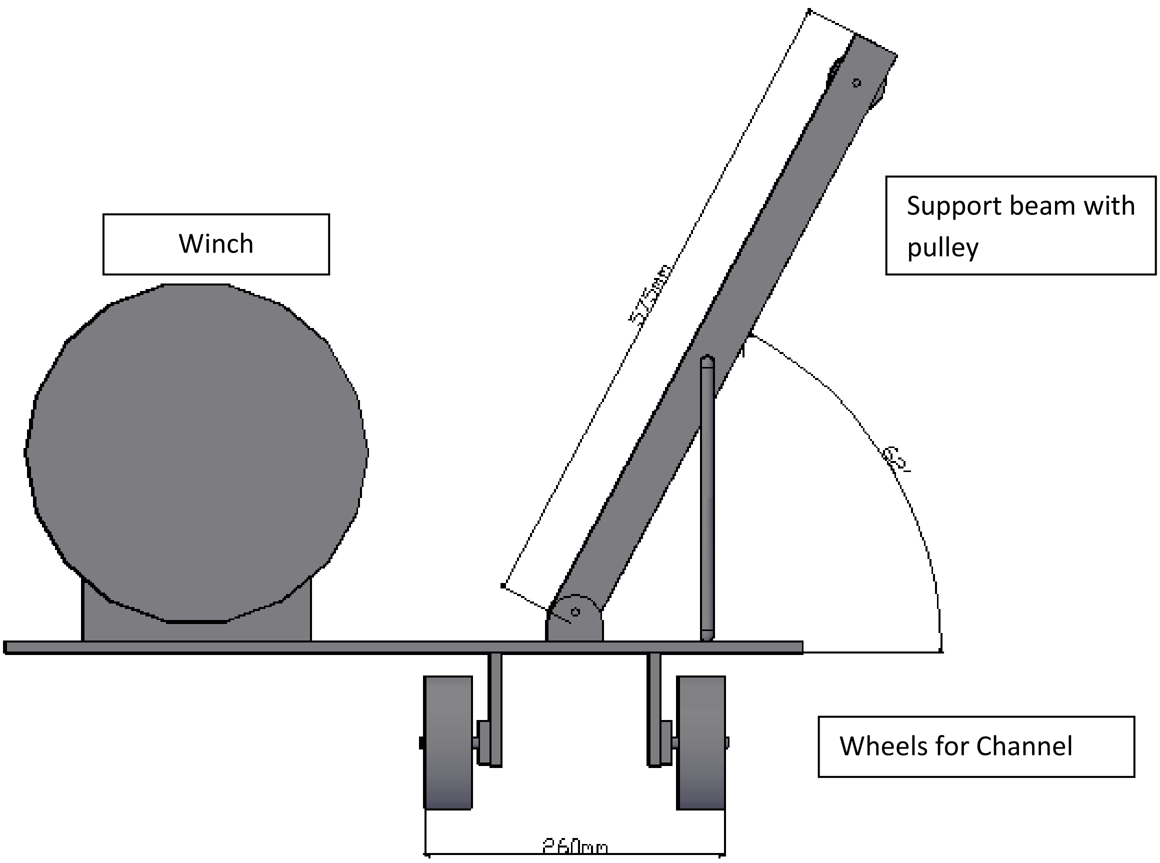
Top view of the detail design glass wall cleaning



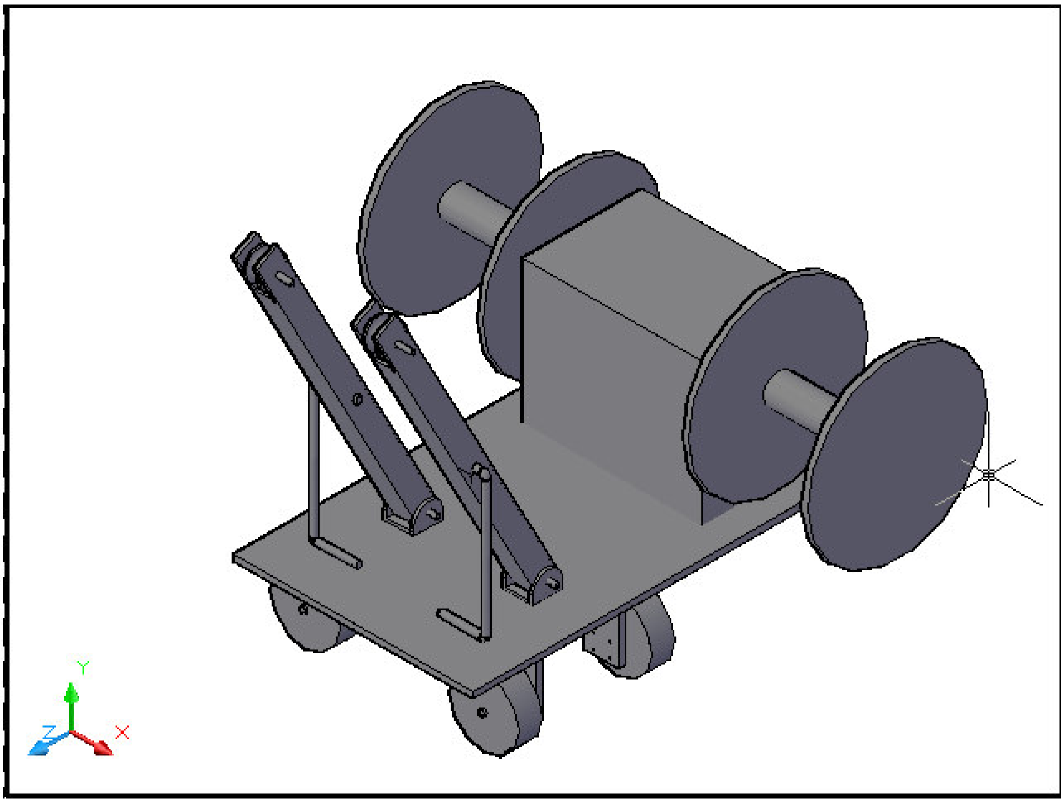
Bottom view of the detail design glass wall cleaning



Side view of the detail design glass wall cleaning



Side view of the support system



Isometric view for the supporting system

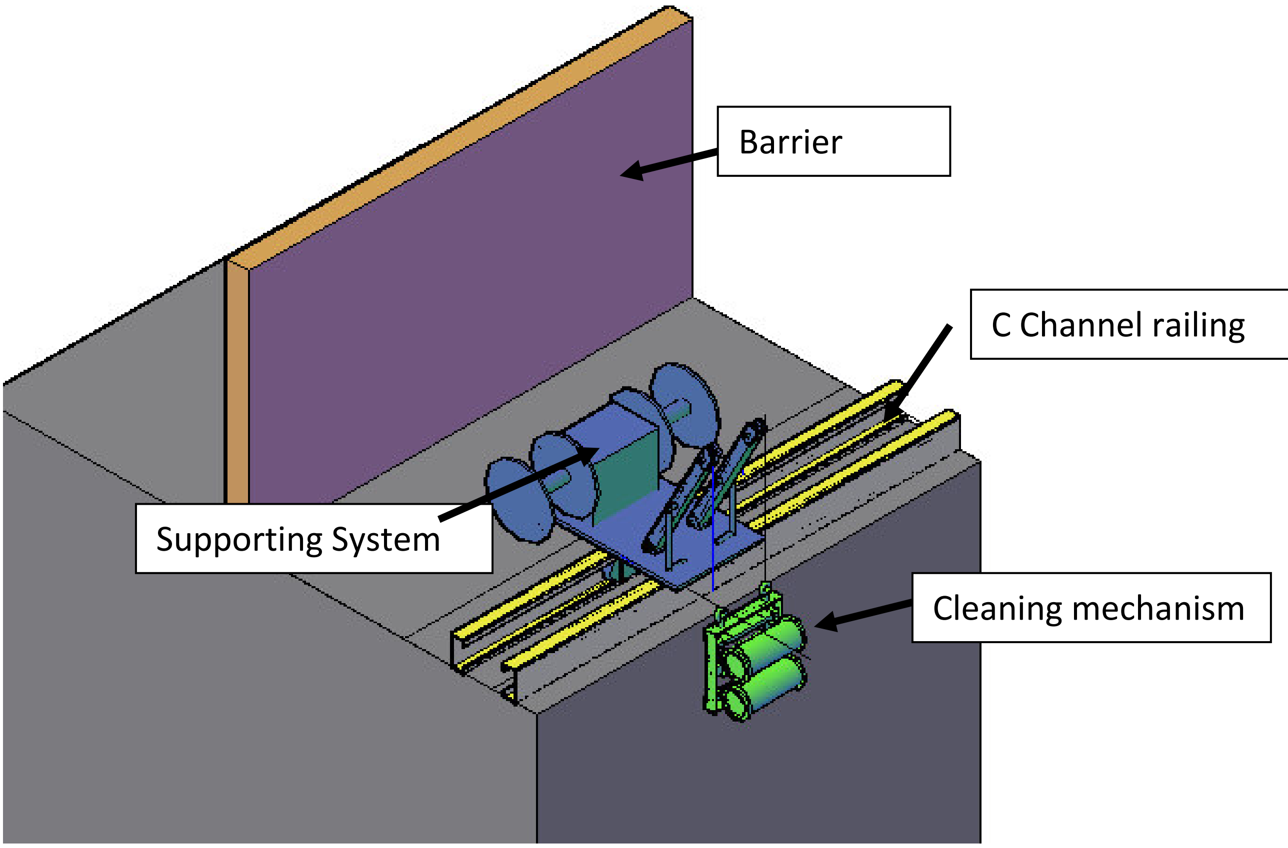


Illustration of a fully completed glass wall cleaning mechanism with translation mechanism on an academic block