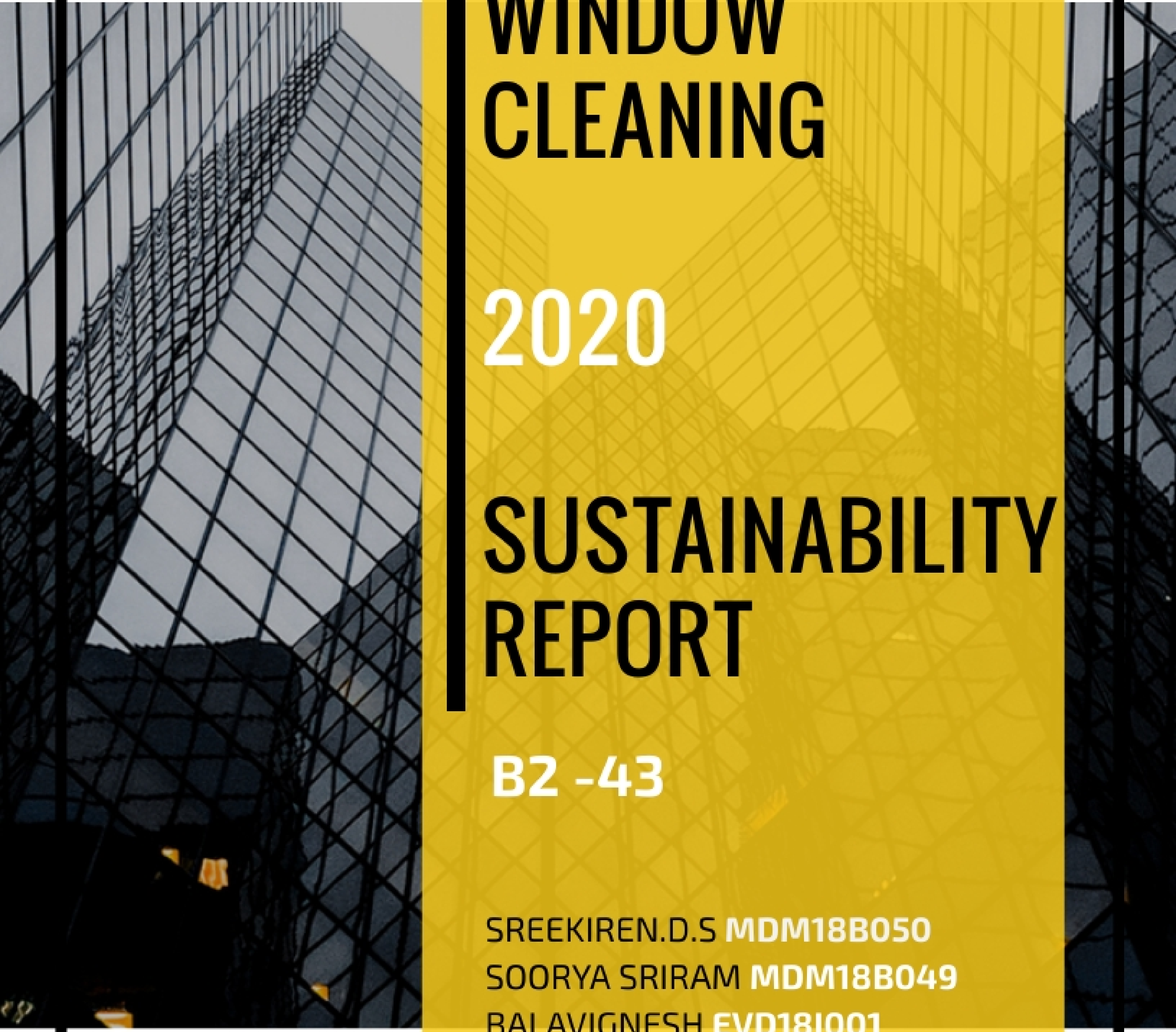

HIGH RISE WINDOW CLEANING

2020

SUSTAINABILITY REPORT

B2 -43

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Introduction

Sustainability is the ability to develop and implement technologies/methodologies, which are self-sustaining without jeopardizing the potential for future generation to meet their needs.There exists increasing demand for the development of various service robots to relieve human beings from hazardous jobs, such as cleaning glass-surface of skyscrapers, fire rescue, and inspection of high pipes and walls. This project is based on a climbing robotic system aimed to clean glasses of high-rise buildings, using suction cups for adhering to the glass

Based on the results of interdisciplinary fields like mechanics, electronics and informatics the autonomous mobile robots are gaining more and more attention. The methods used for movement, actuation and none the last the ability to operate in unknown and dynamic environments give them a great complexity and a certain level of intelligence

The human model is still a challenge for mobility and robot movement. Robot mobility is satisfactorily achieved, in some cases even better with other types of locomotion means, but technical solutions that rigorously reproduce human walking are not yet identified.

The research in this field has a tremendous potential especially in providing new ideas and/or knowledge development.The robotics flagship aims to develop window cleaning robots and artificial intelligence that are economically,socially and environmentally sustainable.

The project's main goals revolve around 3 pillars:

- The identification of new materials, technological approaches and biological principles important to make the robots adapt to people and the environment in which they operate, with bodies of variable shapes, able to grow, learn, deform and find their own energy;
- The study of new models of socioeconomic and legislative systems able to take advantage of a widespread use of robots;
- The development of robots with low environmental impact, reducing growing e-waste through the study of recyclable materials and renewable energy solutions to power robots.

The project will contribute to the affirmation of a new paradigm in robotics, where AI, big data, mathematics, materials and biology participate in a single and coherent vision, to build adaptable machines, with learning, collaborative and effective skills.The mobile robots endowed with platforms and legs with cups are widely spread impractical applications due to high relative forces of locomotion, mobility and good suspension. The disadvantage of increased overall size less disturbs in applications of cleaning and inspection of large vitrified surfaces covering the buildings.

This paper mainly focuses on the analysis of the window cleaning robot based on powerful sustainable tools like LCA,life cycle costing,swot analysis and other tools and obtain the corresponding changes in the design of the model which is more sustainable in all aspects namely social,environment and economical para metrics

UN sustainability goals and product & business alignment towards the goals

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including poverty, inequality, climate change, environmental degradation, peace and justice.

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

The window cleaning process is not completely automated even though cleaning bots are used. Increased number of window cleaning bots will lead to greater electricity consumption to execute the cleaning service which will lead to pollution and global warming.

The unclean soapy water that is obtained after the cleaning process is sufficiently treated and removed of its impurities as per the norms and only then released back into water bodies or used for other activities making sure the people and community involved are not subjected to any ill effects due to consumption of this water.

Unskilled laborers who did not have access to education are provided training, introduction to the importance of conservation of water and reduced amount of electricity consumption so that they exhibit this process in their respective home and society thereby increasing the environmental effects. Women and children involved in manual and scavenging labor activities will now be provided with improved conditions and environment. The employment of women will reduce the number of children being forced into child labor and related activities and improve the community and families involved.Involvement of robots to clean the windows creates a lot of job opportunities from managing the production of the product and leading the company to workers employed in production, supervision and maintenance of the product. This provides opportunities for women in a male dominated industry leading to effective participation at leadership and decision making levels.

Treating our waste water and eliminating the water pollution enables reduced amounts of water borne diseases in the nearby community thereby reducing the cost for health and medical services of the people and that amount can be used for other productive things that increase the economy of the country/community.

Usage of solar panels in the product reduces the amount of energy consumed from the domestic power supply is reduced, energy saved is energy produced.

Window cleaning industry is not a standalone independent industry. It works hand with software and manufacturing companies to provide new solutions in machine learning, AI and this leads to creation of new ideas and jobs in R and D departments of top companies.The interdependent partnerships between industries will lead to the evolution of ideas and jobs and thereby the overall welfare and economy growth of the country. By setting up manufacturing plants in developing countries we provide opportunities to use local technology and research innovation.

Reduced water consumption of our window cleaning robot reduces global water stress and increases the economy in terms of available resources for future use.Involvement of efficient thermal cooling technology reduces the CO2 emission from our robots and reduces the level of greenhouse gas release thereby decreasing the global warming substantially.

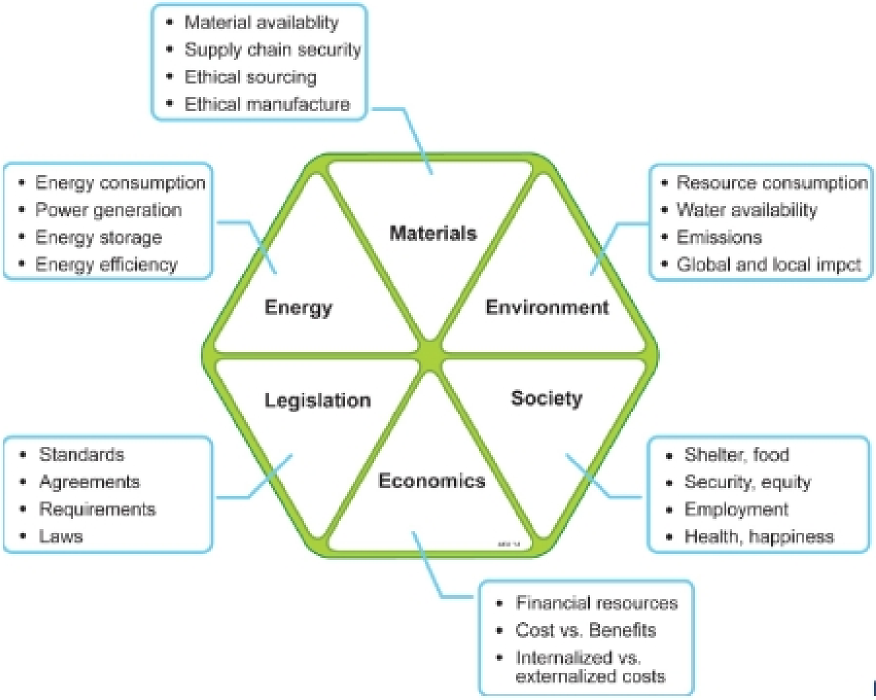
The wastewater generated acts as a source for water treatment plants increasing the economy of water treatment industries.Water provided from tanks is used to cool and reduce the temperature of the hot window cleaning bots. This water which is used to clean windows are brought back to ambient temperature, thoroughly processed and cleaned before being released back into water bodies.

Out of 17 goals,our product and business model is in line with majority of the goals nearly 60 percent making our product more sustainable

ASSESSMENT OF SUSTAINABLE DEVELOPMENT

PRIME OBJECTIVE OF THE ANALYSIS:

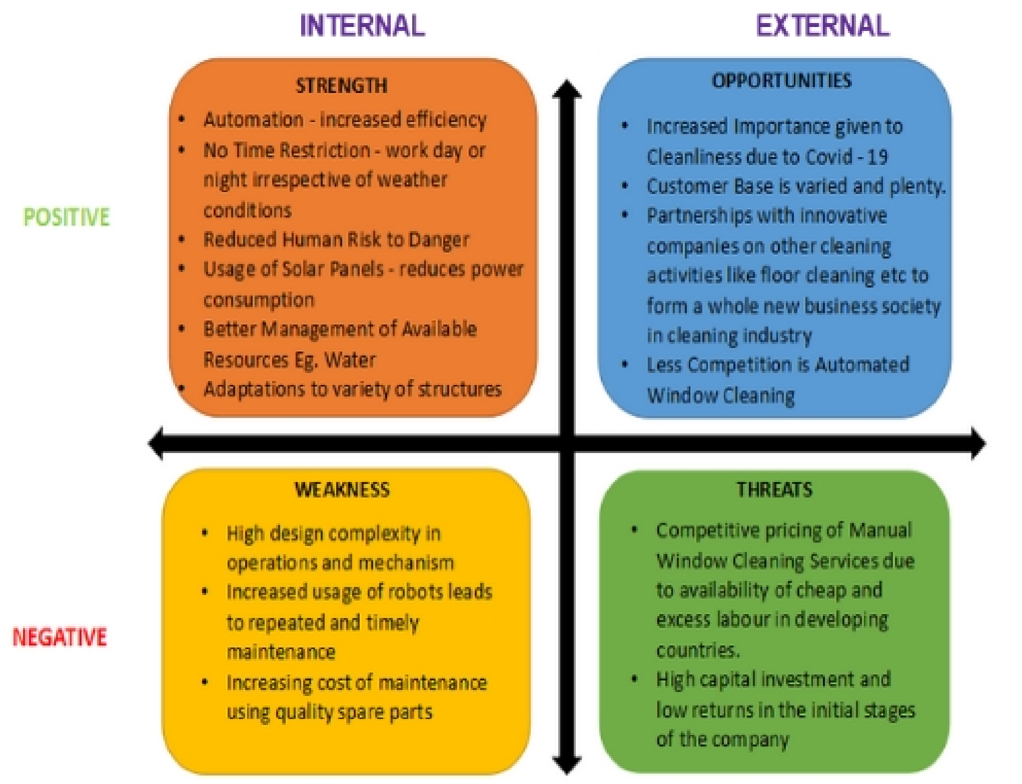
- Reduction of energy consumed from the domestic utility by introducing solar panels
- Reduction of toxicity and carbon footprints by the changing the material from stainless steel/ composite metal to aluminium
- Minimal and efficient usage of resources(Ex. Water, cleansing agents etc.).
- **SIZE SCALE**: 40 automated bots, approximately 4 bots for 1 project.
- **TIME SCALE**: 6 months depending on the return of investment and the response.

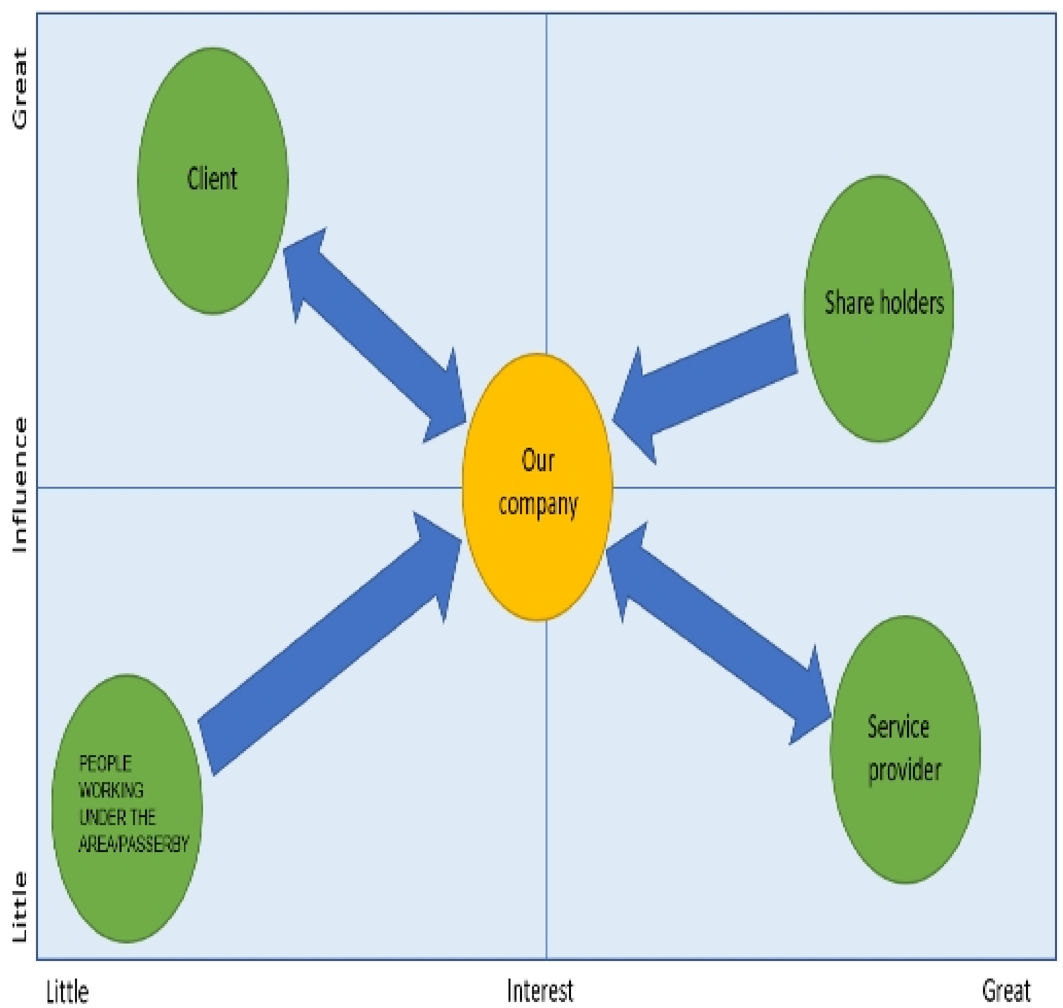


IDENTIFICATION OF STAKEHOLDERS AND THEIR CONCERNS

STAKEHOLDERS	CONCERNS
SERVICE PROVIDER	• PROFIT • SAFETY OF WORKER • SATISFACTION OF WORKER
CLEANER	• CONSOLIDATED AND FACED REQUEST FOR EQUIPMENT • KNOWLEDGE OF REQUIRED SKILL SET FOR SATISFYING THE CLIENT
CLIENT	• QUALITY • COST • EFFICIENCY
PEOPLE WORKING UNDER THE AREA/PASSERBY	SAFETY
SHAREHOLDER	PROFIT

SWOT ANALYSIS & STAKEHOLDER INTEREST MATRIX





Summary of PEOPLE ANALYSIS:

- New opportunities are created due to this pandemic leading to more customers. The UN goal is achieved by creating new jobs replacing the old ones leading to reduction of poverty and improves the well-being of the people of the building.
- The UN Goal of Innovation, Industry and Infrastructure encourages us to responsibly consume resources and to the formation of new partnerships with different companies to expand our operations.
- Usage of renewable energy (solar panels), unclean water is treated before release into water bodies thereby not affecting fauna and achieving the UN goals above mentioned.

FACT FINDING:

MATERIALS

Material	No of units
Motors	4
Single strand wires	2 meters
Multiple strand wires	5 meters
Processor	1
sensors	6
Aluminium	10 kgs
Steel sheet	1
Brushes	4
Battery	1
solar panel	2
Vacuum suction pad	3
Internal PVC pipes	1.5 meters

Bill of materials for one window cleaning robot:

- The supply chain is secure because the materials are directly acquired from the suppliers and no third parties are involved.
- Most of the raw materials that are used for manufacturing our products are available in india and as aluminium is used the product is light weight the power consumed by the product is also low hence the weight of the product is less.
- Plenty of aluminium suppliers exist within Indian and the products are transported using a truck from the source to the destination hence logistics cost is less and plenty of capacity and warehouses exist where aluminium sheets are stored.

ENERGY,POWER AND ENVIRONMENT

In order to obtain energy intensity of components of the product and their carbon footprints,eco audit or life cycle assessment is done in order to see the results of the material selection decision impact on the socio economic and environmental factor.A complete analysis is made in the upcoming report including various factors like transportation,method of manufacturing,end life characteristics etc.

METHODOLOGY

1.GOAL AND SCOPE

The main objective of this study is to provide a Life Cycle Analysis (LCA) for the robotic tools which can handle high rise window cleaning activities but are made with different materials. To fully describe the material and energy requirements for each robotic tool option, this study used cited values or calculated data to conduct an analysis.
The functional unit is set as years of use, which is a standard unit of measure when service delivered is measured by time. In this study, the expected service life for the robotic arms is assumed to be eight years, which is based on the average service life of industrial robots . The goals of this LCA case study include to understand which eco-design strategies result in the greatest environmental performance improvement; to identify which stage will pose the greatest environmental impact during the whole life of the robotic tools; and to determine how the results can be used to better define the functional requirements and design parameters for the robotic tools in the product realization process.

2.SYSTEM BOUNDARIES

In this study, from entrepreneurship and management course we have found the potential markets are middle east countries and the United States of America and also found chennai to be the best place to invest in industry creation considering all the expenses like initial capital investment,taxes etc.Considering the worst case scenario we have assumed the double-arm window cleaning robots used are manufactured in Chennai,India. The manufactured robotic tools are then transported by truck to the chennai Port in Tamilnadu and shipped to Port of Los Angeles in United States of America by ocean freighter; finally, they will be delivered by truck to Temporary warehouse located nearby , which includes a facility dedicated to store the robot's spare parts and equipments related to servicing related activities for the span service in that location . Table 1 shows the distances from the location of the manufacturer of the robotic arms to the location of its user.

Description	Transportation mode	Distance
From double arm window cleaning robot manufacturer to chennai port	Trucks	15 kms
Chennai port to port of los angeles,USA	Ocean freighter	1590.87 km (859 nautical miles)
Port of los angeles to nearby warehouse	Trucks	25 kms

Table 1 the distances from the location of the manufacturer of the robotic arms to the location of its user.

This LCA study will evaluate the environmental impacts associated with all life stages of the robotic tools, which include the pre-manufacturing stage, manufacturing of the robotic arms, use, as well as disposal, reuse or recycle of the robotic arms. To simplify the analysis, the mechanical components of the robot will be included in the analysis, while electrical components (wiring, sensors) will be excluded due to their relatively small sizes and similarity. Power consumptions of the robotic arms will be calculated based on the anticipated requirement of an appropriately sized motor which can fulfill the functional requirements of a robotic arm

3.MATERIALS:

Robotic tools made with three different materials are investigated in this study. Table 2 lists the material breakdown of five major components of a robot which is made with composite materials

Component	Weight	Materials
End effect factors	0.2 kilos	• High strength epoxy carbon prepreg • Polyurethane foam core • Glass surface veil • Nylon edge closures • Aluminium inserts
Wrist 1	1 kilos	• High strength epoxy carbon prepreg • Polyurethane foam core • Glass surface veil • Nylon edge closures • Aluminium inserts
Wrist 2	1 kilos	• High strength epoxy carbon prepreg • Polyurethane foam core • Glass surface veil • Nylon edge closures • Aluminium inserts
Arms	1.2 kilos	Carbon Fiber epoxy composite
Base	2 kilos	Aluminium

Table 2. Material breakdown of the composite double-arm type robot for Window Pane Cleaning

Although metallic materials were deemed less suitable for the specific application which required strict dimensional tolerances and material characteristics, the environmental effect of replacing the composite materials with aluminum has been examined in this study. Table 3 shows the material breakdown of the aluminum double-arm type robot. The increased weight of the aluminum components was assumed to be distributed equally with respect to each component's weight relative to structure

Component	Weight	Materials
End effect factors	0.3 kilos	Aluminium
Wrist 1	1.4 kilos	Aluminium
Wrist 2	1.4 kilos	Aluminium
Arms	1.8 kilos	Aluminium
Base	3.5 kilos	Aluminium

Table 3. Material breakdown of the aluminum double-arm type robot for Window Pane Cleaning

Table 4 shows the material breakdown of a robot whose major components are made with stainless steel. Since, if designed for the same stiffness, an aluminum structure will weigh more than that of the equivalent structure in steel. Also, due to the increased weight of the robot components, the weight of the cast iron base is scaled up for the metallic robots.

Component	Weight	Materials
End effect factors	0.4 kilos	Stainless steel
Wrist 1	2 kilos	Stainless steel
Wrist 2	2 kilos	Stainless steel
Arms	2.5 kilos	Stainless steel
Base	5 kilos	Aluminium

Table 4. Material breakdown of the steel double-arm type robot for Window Pane Cleaning

4.MANUFACTURING

Figures 1–3 show the manufacturing processes of the major components: end effectors, wrists, arms as well as the base.

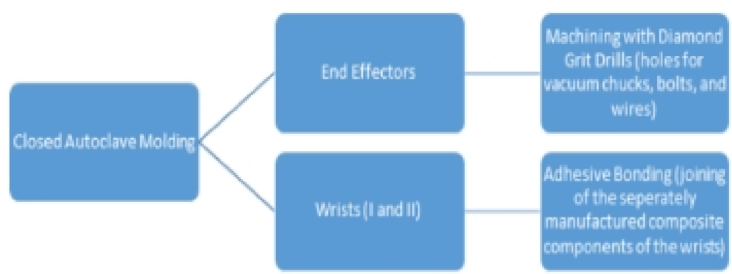


Figure 1. Manufacturing and processing of the end effectors and wrists.

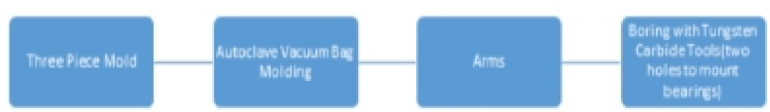


Figure 2. Manufacturing and processing of the arms.

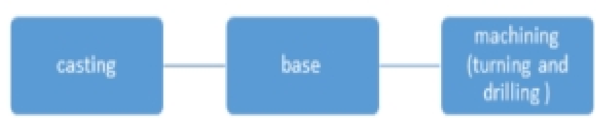


Figure 3. Manufacturing and processing of the base.

5.POWER USE:

The power consumption of the double arm window cleaning robot is calculated based on the rated power of the drive motors of the arms and wrist rotation.Due to the increased weights and size when compared to existing window cleaning bots,more powerful motors would be required for those metallic robots,since for them,not only the motors would have to overcome the increased weight of the metallic components,but the robots themselves would require a larger range of motion to traverse with larger weights.The life operation hours are based on the assumption of twenty hours of operation per day,for a total eight year life span.Table 5 lists the calculated life energy consumption of the motor of these robots.

Motors	Rated power (W)	Materials of effectors	Life hours (Hrs)	Total energy use (kWh)
Arm drive motor	466.3	Composite	58,400	27,231.9
Wrist drive motor	31.9	Composite	58,400	1862.9
Arm drive motor	606.2	Aluminium	58,400	35,401.5
Wrist drive motor	41.5	Aluminium	58,400	2421.8
Arm drive motor	1262.9	Stainless Steel	58,400	73,753.1
Wrist drive motor	85.8	Stainless Steel	58,400	5009

Table 5- power consumption of the robot

Since we have no other alternatives for the batteries given the power consumption we will be using Lead acid batteries.

6.END OF LIFE:

Composite materials pose a challenge for recycling, as they cannot be economically separated into their component categories.

In this study, the composite materials used for the construction of window cleaning double-arm type robots (arms, wrists and end effectors) are assumed to be sent to a landfill at the end of the robot's service life, while the base, made of gray cast iron, can be recycled.

By replacing the unrecyclable composite components (arms, wrists and end effectors) with aluminum or steel, recycling of the double-arm type robotic structure becomes feasible. The metallic components and the gray cast iron base are assumed to be recycled at the end of the robots' eight-year service life

7.RESULTS

Based on the above assumptions and calculations, a LCA model was built with Sustainable Minds software, and the environmental impact generated by the robotic tools can be calculated. Figure 4 shows the total impact of the robotic tools made with three different materials: composite, aluminum and steel

The impacts have been divided into three major categories: ecological damage, resource depletion and human health damage. For all three materials, the largest impact category is human health damage, especially the carcinogenic subcategory, which accounts for more than 50% of the total impacts for all three materials.

Figure 5 shows the environmental impacts generated by the robotic arms during different life stages. The robotic tools made with three different materials have shown a consistent result: the use stage has generated the highest environmental impact.

Figure 6 shows the carbon footprint of the robotic tools during the different life stages. The results are consistent to those shown in Figure 5 for all three robot types; the most carbon emission was generated during the use stage.

Composite

Impact category	%
Ecological damage	
Acidification	3.94
Ecotoxicity	4.62
Eutrophication	0.68
Global warming	20.93
Ozone depletion	0.02
Resource depletion	
Fossil fuel depletion	6.01
Human health damage	
Carcinogenics	51.69
Non carcinogenics	6.93
Respiratory effects	2.81
Smog	2.38

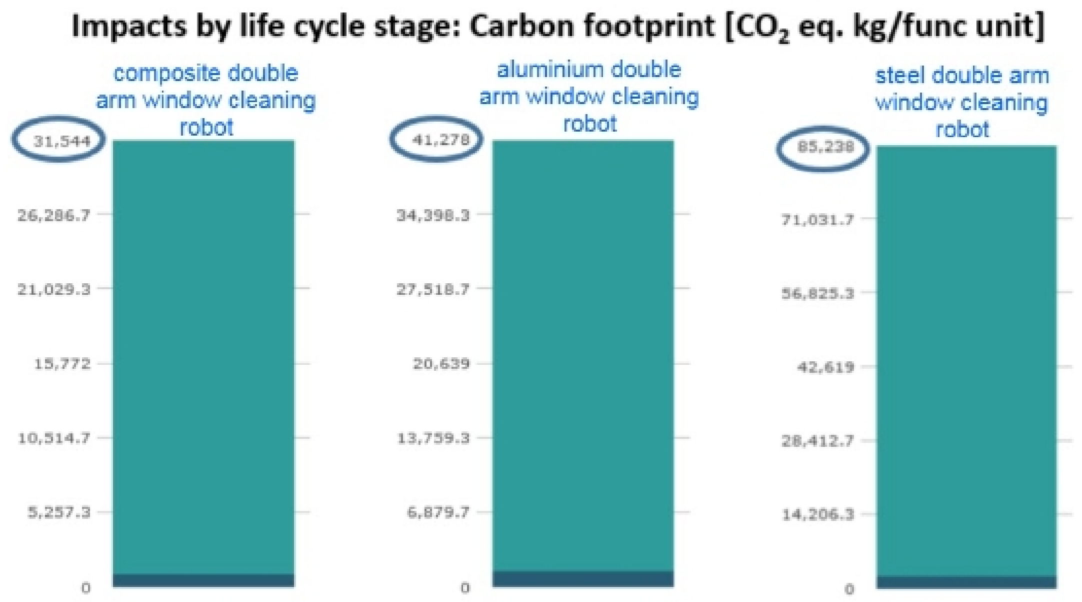
Aluminum

Impact category	%
Ecological damage	
Acidification	3.89
Ecotoxicity	4.64
Eutrophication	0.67
Global warming	20.81
Ozone depletion	0.01
Resource depletion	
Fossil fuel depletion	5.83
Human health damage	
Carcinogenics	52.11
Non carcinogenics	6.87
Respiratory effects	2.81
Smog	2.35

Steel

Impact category	%
Ecological damage	
Acidification	3.61
Ecotoxicity	4.58
Eutrophication	0.62
Global warming	19.25
Ozone depletion	0.01
Resource depletion	
Fossil fuel depletion	5.37
Human health damage	
Carcinogenics	54.98
Non carcinogenics	6.76
Respiratory effects	2.64
Smog	2.18

Figure 5



Total = 3.2×10^4 CO_2 eq. kg/func unit

Lifecycle stage	CO_2 eq. kg/func unit
End of life	0.739
Manufacturing	917
Transportation	6.58
Use	3.06×10^4

Total = 4.1×10^4 CO_2 eq. kg/func unit

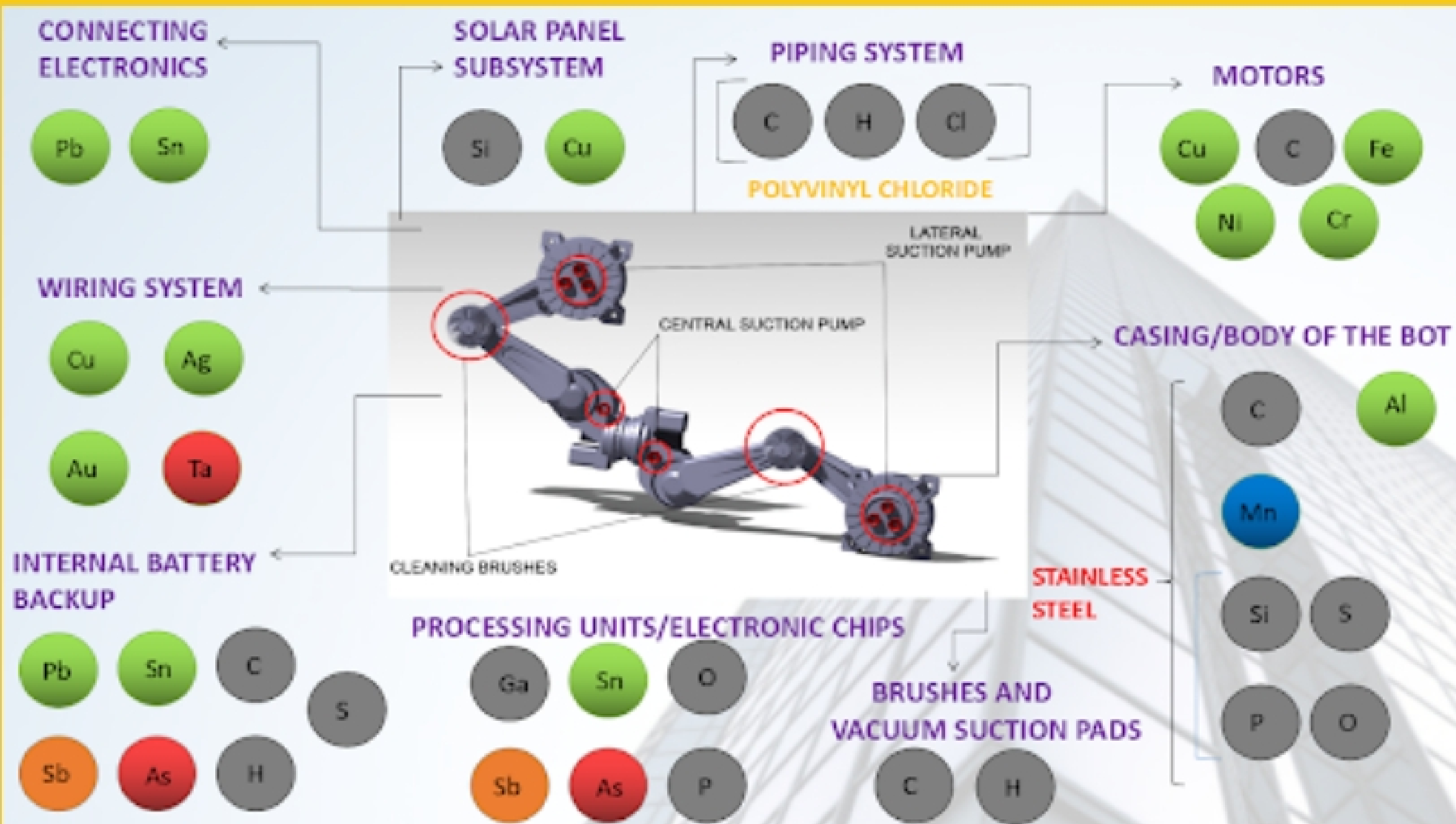
Lifecycle stage	CO_2 eq. kg/func unit
End of life	0
Manufacturing	1.47×10^3
Transportation	5.93
Use	3.98×10^4

Total = 8.5×10^4 CO_2 eq. kg/func unit

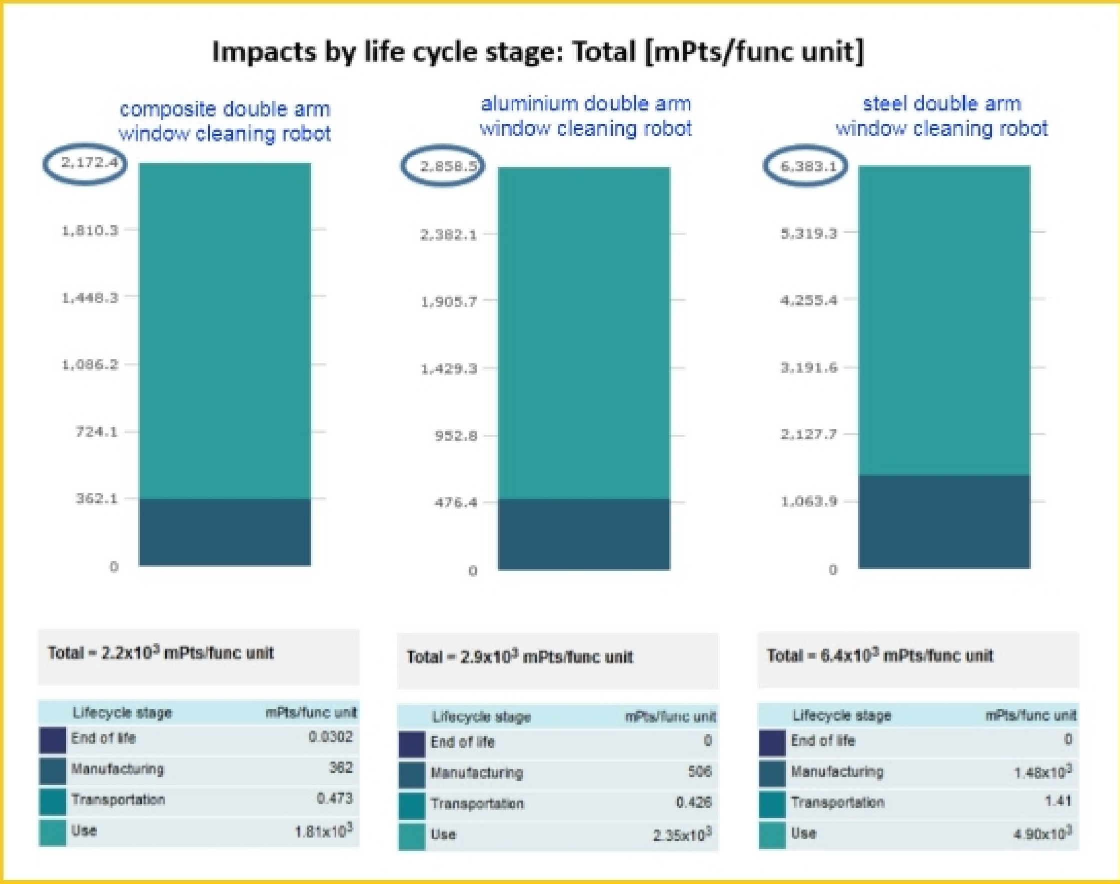
Lifecycle stage	CO_2 eq. kg/func unit
End of life	0
Manufacturing	2.33×10^3
Transportation	19.7
Use	8.29×10^4

Figure 6

IDENTIFICATION OF COMPONENT MATERIALS AND ANALYSIS ON RECYCLABILITY RATES



1%	LESS THAN 1 % RECYCLE RATE	50%	25 %-50% RECYCLE RATE
10%	1 %-10% RECYCLE RATE	75%	GREATER THAN 50% RECYCLE RATE
25%	1 0%-25% RECYCLE RATE		NON METAL OR RECYCLABILITY RATE UNKWON



Using eight years as the functional unit (the expected service life for the robotic arms), the kilograms of equivalent carbon dioxide released over the life of the window cleaning double-arm type robotic arm was thus determined. It will be 32,000 kg when composite material was selected for the arms, wrists and end effectors; 41,000 kg when replaced with aluminum (of equivalent strength and damping ability); and 85,000 kg when replaced with steel (of equivalent strength and damping ability). The aluminum double-arm type robot thus represented an environmental performance decrease of 32% from the composite material, and the steel concept represented a decrease of 190% from the composite material (shown in Figure 7).

	Impacts / functional unit mPts/func unit	CO_2 eq. kg / functional unit CO_2 eq. kg/func unit	Performance improvement from reference mPts	Performance improvement from reference %	Units of svc delivered Svc. Units	Assessment type
composite double arm window cleaning robot	2.2×10^3	3.2×10^4			1	Estimate
aluminium double arm window cleaning robot	2.9×10^3	4.1×10^4	-690	-32%	1	Estimate
steel double arm window cleaning robot	6.4×10^3	8.5×10^4	-4.2×10^3	-190%	1	Estimate

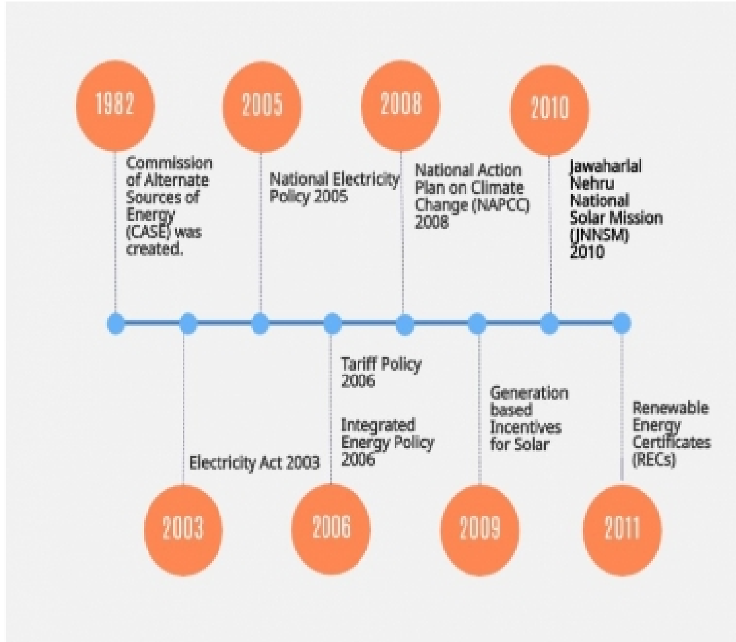
INFERRENCES FROM LCA

LCA analysis of the double arm window cleaning robot made with three different materials; composite, aluminum and stainless steel, has shown that the most significant impact generated by the robotic arms is carcinogen, while the use stage of the robotic arm's life has the greatest environmental impact. As a subcategory of human health damage, carcinogens accounted for more than 50% of the total impact for all three materials. During use, the power consumption increased with the weight of the aluminum and steel double arm window cleaning robots which offsets the advantage of recycling these materials. With the composite design as the reference, the environmental performance of the double arm window cleaning robot decreased 32% using aluminum and 190% using steel for the end effectors', wrists' and arms' material. This analysis, performed using Sustainable Minds software, also leads to the conclusion that robotic tools with lighter weight and higher energy efficiency will generate lower environmental impact.

REGULATION

he Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters relating to new and renewable energy. The broad aim of the ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country.
Policy infrastructure in the renewable energy sector in India took shape with the foundation of the Commission of Alternate Sources of Energy (CASE) in 1981, in the Department of Science & Technology. It became an independent Department of New Energy Sources (DNES) in 1982 and a full-fledged Ministry in 1992.

Electricity Act, 2003 : The act provides a framework for the overall growth of the electricity sector in India. It gives provisions for preferential tariff and quotas for opting for renewable energy. Mandatory procurement of renewable energy for distribution licensees and facilitation of grid connectivity were incorporated.



MRAI promotes recycling in india.It aims to minimise waste and ensure that the aluminium used can be reused, recovered or recycled. To comply, a producer must join a registered compliance scheme. The legislation applies equally to aluminium and steel bodied bots.

SOCIETY

Most of the customers don't really care about the composition of the product, all they care about is the efficient usage of their resources and cleaning. Since they care so much about the utilization of their resources, placing solar panels and reducing the power dependency is much appreciated by them. Also better utilisation of water which is taken from the overhead tanks is also appreciated by them.

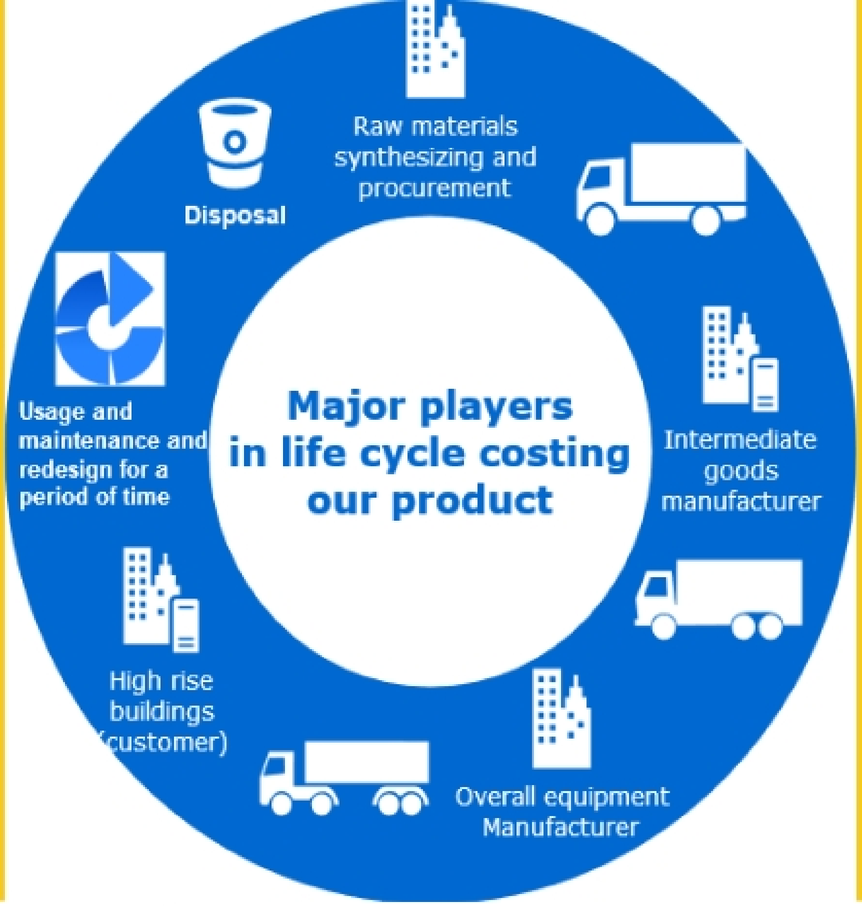
ECONOMY

In order to understand the economical advantage of the above mentioned sustainable changes we must use a powerful tool like life cycle costing

LIFE CYCLE COSTING

Life cycle costing, or whole-life costing, is the process of estimating how much money you will spend on an asset over the course of its useful life. Whole-life costing covers an asset's costs from the time you purchase it to the time you get rid of it.

The below mentioned cost analysis covers the detailed costing in the overall manufacturing segment,its transportation,installation or service cost and its maintenance cost.According to the life cycle costing methodology the costing in the preprocessing segments above the overall equipment manufacturing segment is 1.5 times approximately the cost of successive ones.This only apply to the companies whose suppliers are small scale manufacturers.



Inbound logistics	Operations	Outbound Logistics	Service
Motor: Selling Price - 4000/pc *4pc = Rs 16000 **Wires:** Single strand : 15/meter*2 meters Multiple strand : 30 / meter *5 meters Total Selling price : 180 **Processor and Accessories:** Selling price : Rs 3000 **Aluminium and Steel :** Selling Price : Rs 143.67 /kg * 10 Selling Price : Rs 300 a sheet for steel Total Selling Price - Rs 1736.7 **Brushes - Plastic/ Biodegradable :** Selling Price : Rs 1000/piece *4= Rs 4000 **Battery :** Selling price - Rs 1500 **Vacuum Suction Pump :** Selling Price - Rs 900 * 3 = RS 2700 **Internal PVC Pipes :** Selling Price - Rs 180/3 = Rs 90 **Total Selling Price of Raw Materials :** **Rs, 27, 000**	**Workspace Rental :** Rs 5000 **Labour :** Rs 1200 per person * 5 **Electricity and Water bills :** Rs 4000 **Redesigning and engineering depending on Customer :** Rs 5,000 **Cost incurred :** Rs 15000	**Warehouse Storage :** Selling Price - Rs 20 per/ft^2 * 400 ft^2 Total Selling Price - Rs 8000 **Transport Vehicle - Mini Tempo including driver labour / hr :** Selling Price - Rs 2000	**Investment :** Rs 75, 000 per robot Expected Cleaning Service would require 2 to 4 robots hence a total investment will be around **Rs 8, 50, 000** would be put in if the product excels. The entire cleaning process is expected to occur for **2 months** depending on the customer building.
Total Selling Price : **Rs 33, 000** **Margin : Rs 6000**	**Total Selling Price :** **Rs 60 ,000** **Total Margin :** **Rs 7, 000**	**Total Selling Price :** **Rs 75, 000** **Total** **Margin :** **Rs 5000**	**Investments in Robot:** **Rs.75,000/bot** **Total Investment :** **Rs.8,50,000** **Our selling price:** **Rs. 1,60,000 for two months**

Inventory robot stock numbers = (75000*2)=
Rs. 150000
Inventory spare parts cost=Rs.100000
Transportation charges for transfer of goods between preceding industry varies depending on the location of each industry with respect to one another and other parametric costing o the preceding industry are give under outbound logistics

DEPRECIATION COST:

The percentage change of the Quote Currency relative to the Base Currency is

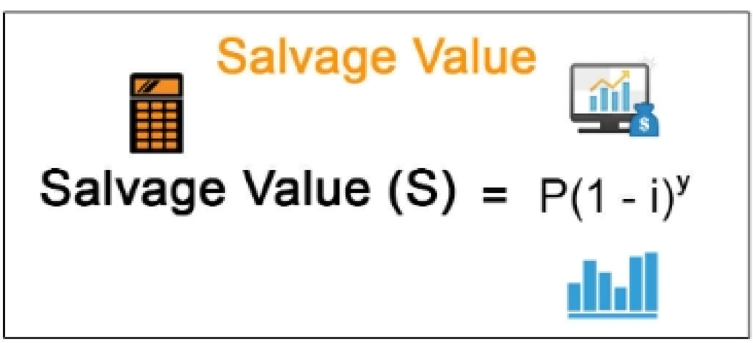
Percent Change=(V1−V2)/|V2|×100

A positive change is appreciation and a negative change is depreciation.

According to this formula,depending on the market and other factors prevailing at that point of time in the future,the value of 1 INR reduce over a period of time,Hence the value of the robot over a period of time before disposal

DISPOSAL:

Salvage value is the estimated resale value of an asset at the end of its useful life. It is subtracted from the cost of a fixed asset to determine the amount of the asset cost that will be depreciated. Thus, salvage value is used as a component of the depreciation calculation



Manual Window cleaning Services are provided at Rs 3000 per day and depending on the building architecture takes around 4 months.

We will break even in 1.5 years and aim to make profit further. The entire cleaning process is expected to occur for 2 months depending on the customer building.

SYNTHESIS:

NATURAL CAPITAL:

There are vast differences in the embodied energy and carbon footprint of steel and aluminium are too small to be significant. This is because of the high recyclable content of aluminium since it is lighter than stainless steel and according to the LCA, the deep drawing of aluminium to make automated bots is much less energy intensive as compared to the equivalent processing of steel. The supply chains for both metals are robust with no global or national shortages. Use of solar panels makes the automated bots less energy intensive when compared to the case where we don't have any solar panel installed in the bot. The recharging of batteries is mostly dependent on the domestic power supply which is generated by burning coal and lignite, but this dependency is reduced by installing solar panels.

HUMAN CAPITAL:

An automated window cleaning bot ..... Is well...... just a bot. The material of which it is made carries no emotional, cultural or aesthetic baggage that needs to be considered. But the better utilization of the resources affects the customers mentally.

MANUFACTURED AND FINANCIAL CAPITAL:

If the prices of steel and aluminum are directly reflected in automated window cleaning bot prices, a switch to aluminium from steel could provide an annual saving. According to our Life Cycle Assessment, we have found out the weight of the automated bot increases when steel is used in place of aluminium. Though the volume of material used would be the same, the total weight of steel is greater than that of aluminium and hence the total cost of investment increases. Usage of solar panels increases the manufacturing cost but in the long run the returns are higher than expected. Better utilization resources increases the profit

SYNTHESIS MATRIX:

Six Sectors		Three capitals	
	Natural capital	Human capital	Manufactured capital
Materials	(+) Fact 1 (-) Fact 3	(+) Fact 1	(-) Fact 1 (-) Fact 5
Energy		(+) Fact 5	(-) Fact 2
Environment	(+) Fact 4	(+) Fact 3	
Legislation			(-) Fact 4
Society	(+) Fact 5		
Economics			(+) Fact 6
Synthesis	Gain	Gain	Loss

REFLECTION

By implementing these objectives into our product, the product will be preferred by many of the customers since the resources are utilized to the maximum extent and the improved efficiency compared to other alternatives. Though the manufacturing costs increase, the profit which we gain in the long run is much higher. By implementing these objectives the harm done to the environment is reduced significantly since the product is less energy intensive when compared to other automated solutions. Moreover the carbon footprints and toxicity levels are also reduced extensively.

ENVIRONMENT IMPACT ASSESSMENT

	Production	Use	Disposal
Materials	Steel , Silicon, Aluminium , Wires, Chemicals for cleaning, Water, Polymers , Rubber	Water, Biodegradable Detergents, Polymers, Ropes and wires	Chemicals used for water treatment, Aluminium and Iron are sent as scrap to garbage yards after usage, Petrol and diesel used for burning
Energy	Raw materials have to be transported to the warehouse leading to usage of fossil fuels. Electricity is used for manufacturing the final robot.	Solar Energy is used to recharge and power the bot for its activities. High consumption of electricity to execute the cleaning activity.	Electricity is used for water treatment and for reusing the metal bodies for other purposes.
Toxicity	Water mixed with chemicals are used in the cleaning process. Unwanted heavy metal dumping after manufacturing of robots.	Lubricant and unclean water with dirt and dust particles may not be collected effectively leading to land and soil pollution in that area.	Wastes such as E-wastes (processors,sensors and motors) cannot be recycled and they are not biodegradable.

Apart from lca we use a powerful tool like met matrix toot against the impact of our product against environment.The unclean soapy water that is obtained after the cleaning process is sufficiently treated and removed of its impurities as per the norms and only then released back into water bodies or used for other activities making sure the people and community involved are not subjected to any ill effects due to consumption of this water.Treated clean water release into water bodies does not affect the sea life and the underwater vegetation Usage of solar panels in the product reduces the amount of energy consumed from the domestic power supply is reduced, energy saved is energy produced.Since we are in partnerships with various industries, waste generated in one is reused by others for innovation and product realization in such a way that waste is minimized and resources are reused and recycled.Involvement of efficient thermal cooling technology reduces the CO_2 emission from our robots and reduces the level of greenhouse gas release thereby decreasing the global warming substantially.Water provided from tanks is used to cool and reduce the temperature of the hot window cleaning bots. This water which is used to clean windows are brought back to ambient temperature, thoroughly processed and cleaned before being released back into water bodies.

PRINCIPLES OF DESIGN FOR SUSTAINABILITY AND THE PRODUCT MODIFICATIONS

SELECTION OF LOW IMPACT MATERIALS

MAGENTOCALORIC COOLING SYSTEM

Environmentally friendly lanthanum-iron-silicon alloy as a magnetocaloric materialA magnetocaloric cooling system requires no harmful refrigerants whatsoever. We are using an environmentally friendly lanthanum-iron-silicon alloy as a magnetocaloric material, which heats up when a magnetic field is applied and cools down when the field is removed.This reduces the effect of ozone depletion due to harmful refrigerants like CFC's

ALTERNATIVES FOR SURFACE TREATMENT-BONDERITE TWO STEP PROCESS

Due to different surface properties of steel and aluminum body components, the BONDERITE two step process pre treats them in two stages. This allows more aluminum to be used, while reducing the disadvantages of the current process. Energy and chemical use decrease during the production process, plus servicing expenses, the associated downtime and the waste volumes are reduced. This as a whole becomes the best sustainable choice for surface treatment of metal bodies.

MOLDED INTERCONNECTED DEVICE (MID)

Molded interconnect devices (MID) are realized as
miniaturized printed circuit with a great design flexibility and environmental benefits and does not use materials like pcb which are toxic rather prints circuits which embedded in the surface of the molds and metals which creates connection in between

RENEWABLE MATERIALS

ALTERNATIVE TO EXHAUSTIBLE RESOURCE POWERED ELECTRICITY

Silicon is the leading material used for constructing solar panels and cells. Whilst there is no shortage of the silicon dioxide used to create the silicon photovoltaic cells it takes an enormous amount of heat to eliminate the oxygen attached to it. Manufacturers have to use an electrode arc furnace to heat silicon dioxide to the required temperatures of between 1500-2000 degrees Celsius. Viable perhaps, but the unfortunate side effect is a higher emission of greenhouse gases.

Perovskites have been widely touted as an alternative material to manufacture solar cells. With no silicon dioxide required, perovskites represent a clean method of solar cell production.

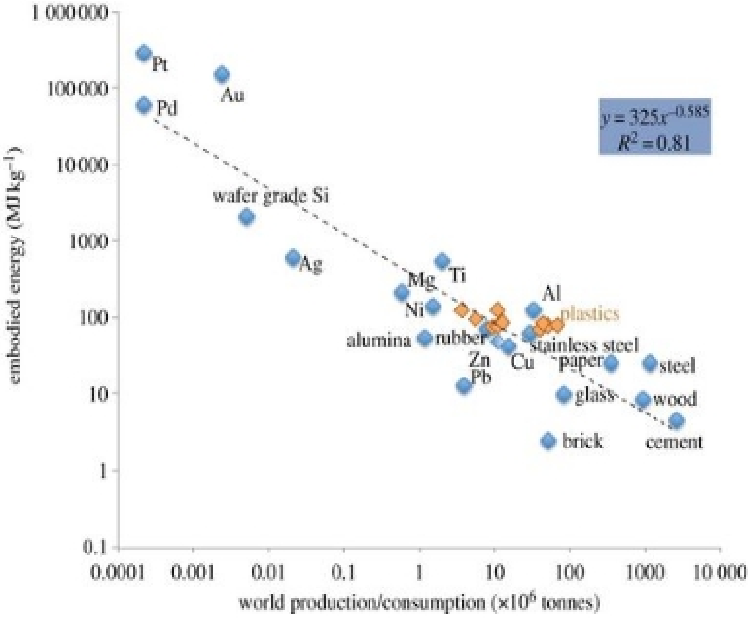
Hence using solar cell manufactured from perovskites as substitute for lead acid batteries for internal backup power system will reduce overall emission in manufacturing the solar cell as well as the best substitute for fuel powered electricity

One of the areas that has come under increased scrutiny is window panel cleaning and the enormous task of keeping tens of thousands of PV panels clean and free of dust – and doing so consistently and in such a way that the panels have long-term protection from damage.

Until recently, cleaning services have failed to evolve to meet the challenges of tomorrow's smart grid, relying on what's been an embarrassingly low-tech solution: dousing row upon row of gleaming PV panels with untold millions of liters of water every year, to be cleaned by a team of manual laborers with brushes.

First, the problem of water: given the dire scarcity of water in our country, Under that maxim we've developed our cleaning technology to be mostly water-free, relying on a unique microfiber cloth to gently wipe panels clean which makes the water consumption less when compared to the existing

LOW ENERGY CONTENT MATERIALS



From LCA analysis, by comparing the window cleaning robotic arm made of composite material, aluminum and steel one could infer that fossil fuel depletion, eutrophication, carcinogenic emission is more in the case of aluminum when compared to steel and also from the embodied energy versus consumption graph we could see that steel occupies the least in the graph inferring that steel is more available than aluminum and the energy intensity is also less in the case of steel .Hence steel is used to make major body parts which supports the LCA analysis

RECYCLED MATERIALS

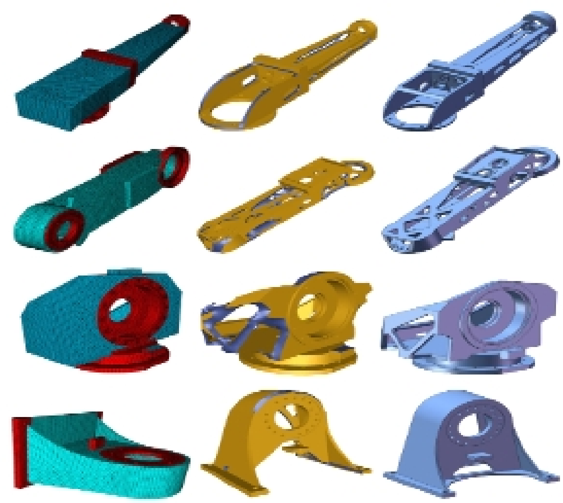
USAGE OF SECONDARY METALS SUCH AS STEEL IN OUR CASE - STEEL SCRAP RECYCLING AND AS A RESULT NEW MARKET EMERGING OUT FOR RECYCLING STEEL

Steel is a material most conducive for circular economy as it can be used, reused and recycled infinitely. While iron ore remains the primary source of steel making, used or re-used steel in the form of Scrap is the secondary raw material for the steel industry. Hence from the above inference since we are using steel as the major material for robot body so secondary steel can be used for this purpose. And this increases the demand for recycled steel thereby expanding opportunities to business reliable on recycling the worn steel

RECYCLABLE MATERIALS

As steel can be used, reused and recycled infinitely once the robots wears out after a long time it can be supplied to steel recycling industries the plastics which are used for holding the cleaning brushes and the rubber suction pump can be recycled and can be used for other purposes for other industries. And the water after cleaning which contains dirt, cleaning chemicals and other particles can be sent to water treatment plant and can be reused thereby attaining sustainability in most of the aspects.

REDUCTION OF MATERIAL USAGE



As mentioned in the above image, the robotic arm, the connecting link, the base and the clamper when subjected to topological optimization design analysis reduces the design with reduced material consumption serving the same purpose and withstanding the same force both statically and dynamically.Through the topological calculation and corresponding optimization, an optimized model can be obtained, and then an actual product processed based on the optimized model was obtained. The results of corresponding static kinetic analyses showed that the weight can be reduced 17.9% and lower order nature frequencies were increased. At the same time, the working performance remained same.A self-designed experimental platform and corresponding experimental method were employed to validate the effectiveness of the topological optimization of the structure. The repeatability tests using three different loads and three different moving speeds for the window cleaning robotic arm were conducted. The results showed that the repeatability of the optimized arm of the window cleaning robot was approximately the same as that of the original robot.

REDUCTION IN (TRANSPORT) VOLUME

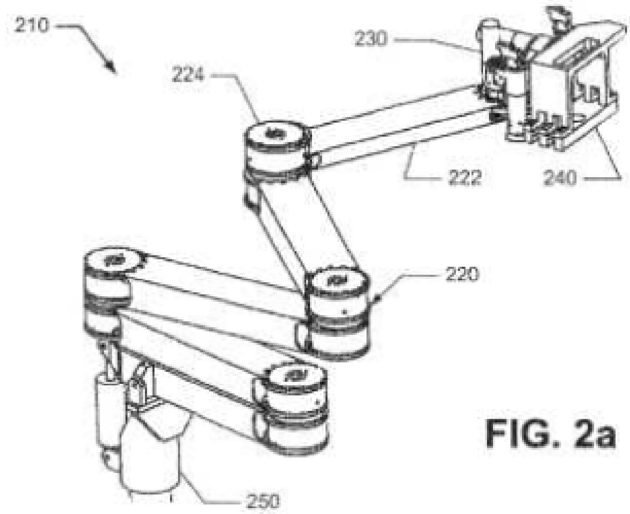


FIG. 2a

The window cleaning is made in such a way that it is foldable or suitable for nesting which reduces the amount of space required for transport and storage by decreasing the robot size

USAGE OF MODULAR COMPONENTS

Also the robot is made in such a way that most of the parts are easily attachable and detachable hence the transporting volume even further decreases

OPTIMISATION OF PRODUCTION TECHNIQUES

USAGE OF STRONG ADHESIVES INSTEAD OF WELDING AND CONDUCTING ADHESIVES INSTEAD OF SOLDERING

Unlike welding, structural adhesives have the ability to maintain the integrity of the bonded materials because there is no metal distortion or weakening due to heat when using adhesives.

Structural adhesives can also increase the stiffness of structures and provide the necessary fatigue and force resistance.

Adhesives have the ability to eliminate the stress concentration caused by spot welds, rivers, screws, and other mechanical fasteners while maintaining surface integrity. Whereas a rivet or screw hole in a substrate concentrates the stress at the hole, which can potentially decrease the physical properties of the substrate, adhesives spread the load over the entire bonded area.

usage of manufacturing machines in the production lines which are capable of doing multitasking (i.e. turret embedded with large number of tools to perform multiple operations in a single machine) such a turning, taper turning and facing and its respective qualitative and quantitative checking can be combined into a single process. This reduces the cost and energy consumption of separate machines

- Usage of renewable energy resources like solar powered or bio gas powered manufacturing plant which reduces the use of exhaustible resources like fossil fuels .

- Making floor plan in such a way that one machine in the production line handles parts in two parallel production lines which reduces the cost as well the energy consumption

In order to minimize the material waste in waste intensive process like turning, milling, facing, pressing and punching etc one of the first ways to minimize waste production from milling operations is to collect and recycle the metal chips/debris produced by the milling process. In most manufacturing centers, this is done via a third party.

Hence, we are using specialized equipment to recycle and reuse metal swarf internally or we must find an effective alternative such as 3d printing where wastage of material is very low

IN house recycling can be followed where the scrap/swarf from the process like milling, turning, pressing etc., are send to recycling plant through conveyors where they are processed which reduces the cleaning area ,generate less wastes, and increases efficiency of in-company re-use and recycle systems for the remaining waste.

The manufacturing plant must be designed in such a way that waster materials which are toxic in nature generated is redirected/routed through conveyor lines or any other mode of transport where human contact with waste material is less and even if persists,accordingly safety equipments are provided to the workers

OPTIMIZATION OF DISTRIBUTION SYSTEMS

- **Less/cleaner/reusable packaging**

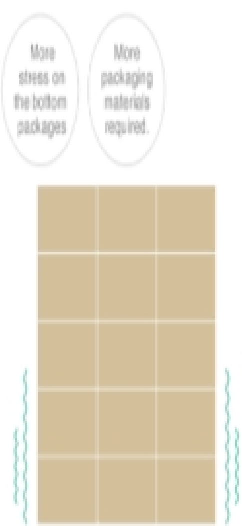
The use of specialized vehicles to transport from one destination to the other leads to minimum usage of packaging material. Our robot which is approximately 1.5m length and 0.85m in width will be accommodated in the vehicle either by using precast molds or tying to the base/ walls of the truck. Hence shock absorbing material such as rubber dampers or renewable foam pads in small quantities are only required to hold the bot in place.

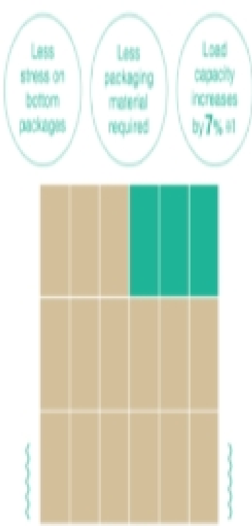
- **Energy efficient transport mode**

The target audience for our cleaning service are companies in high rise buildings. Energy efficient transport mode and logistics are employed since our warehouse is located on the outskirts of Chennai, the robots will be transported from the warehouse to the customers via lorries. Ships will be employed only when the need arises and our clients require us to export the products across countries.

- **Energy efficient logistics**

There won't be much export of the product in the initial stages of our service. We will be setting up local warehouses. From the local warehouses the bot will be transported to the destination with the help of trucks. The bots will be placed in a way such that more bots can be transported by the same truck(upright instead of flat). This makes the logistics energy efficient.





- **Involve local suppliers (distributed economies)**

Before the robot becomes established in the industry and we are able to employ truck companies to make personalized trucks, we will be employing local truck companies to transport our robots to various locations hence reducing the manufacturing costs of trucks in the initial stages.

REDUCTION OF IMPACT DURING USE

- **Low energy consumption**

Identification of optimum components that provide the maximum efficiency is employed to make the robot execute its functions in the best possible manner consuming minimal energy but at the same time not compromising the quality of the service. Solar energy has been utilised to make the bot as energy efficient as possible and a power shutdown button has been provided as an override for the customer. Whenever some part of the robot stops functioning an immediate alert will be provided to the customer and the override stop button will start blinking. Water drawn from the tank is passed through the internal components, using the concept of heat exchanger and principle of convection parts that get hot generally will be regularly cooled.

- **Energy Source**

Rechargeable lead acid Batteries are used to power the bot. Usage of solar panels make sure that a significant amount of the battery is charged by solar energy during the operation and the rest of the battery is charged using domestic power. This reduces the consumption of electricity to power the robot day/night reducing carbon footprints.

- **Fewer consumables needed**

The water used for cleaning the windows requires a high level of purity mixed with the right quantity of soap/detergent. Biodegradable filters are placed at apt positions and clean water is then employed for the cleaning activities. The water which is used for cleaning the windows will be used to cool the bot. Water will be taken from the high rise building itself. In the first stage the water will be made to flow in tubes around the bot so that it cools down the bot, then this water will be used for cleaning. The spilled out water during the cleaning water will be collected and reused as well.

- **Cleaner consumables**

The unclean water with dust and dirt particles is thoroughly treated before it is released into water bodies or used for other activities. This is done by collecting the water that is used for cleaning is once made to flow through filters before it is released into water bodies.

- **Reduce wastage of energy and other consumables**

The pipes connecting overhead tanks with the robot are tightly fitted so as to prevent any spillage or leaks of water and this water is channeled within the bot in a such a manner that only heat exchange takes place and no leakage happens within the bot to prevent internal parts from getting damaged.

- **Health supporting, social added value**

The outer body of the robot has been identified to be made of aluminum as compared to stainless steel or composite body to reduce the toxicity once the clean bot is to be reused after it wears out. This careful analysis has been done after identifying the time taken for material degradation and its toxicity levels.

OPTIMIZATION OF INITIAL LIFETIME

- **Reliability and durability**

Usage of high quality material, maintaining the product frequently, repairing the robot frequently, interruption upon adverse environment and user alert system makes the robot more durable and reliable for the user.

- **Easier maintenance and repair**

Each subsystem in the robot is an intelligent system. Hence if one subsystem is malfunctioning it will be indicated by the system which makes it easier to maintain, repair and replace the subsystem which is not working properly

- **Modular product structure**

For easier maintenance, repair and for implementing intelligent system concepts the robot components are made modular so that part can be detached and attached as per need.

- **Classic Design**

The robot has been designed incorporating the movement of a spider and sticks onto the walls similar to a lizard. The cleaning mechanism involves a 360 degree rotation of its arms. Drawing inspiration from nature, the robot has been designed to be attractive at the same time functional.

- **Strong product-user relation**

The robot will be able to adapt to different structures which makes the product fit-in in almost all possible situations, the robot will be able to clean the windows more efficiently by using minimal resources which satisfies the user and strengthens product user relationship.

- **Involve local maintenance and service systems**

The product will be stored, maintained and repaired at local warehouses setup in different areas depending on the need

OPTIMIZATION OF END-OF-LIFE SYSTEM

- **Re-use of product**

The bot has been designed in such a manner that is aesthetically very pleasing and is very different from the existing robots in this industry. The entire model is composed of modular components hence when different parts having different lifespans wear at different rates certain parts can be reused by attaching and detaching older parts.

- **Remanufacturing/refurbishing**

The manufacturing line will consist of different assembly lines that will help in easy production of individual parts. The individual parts are easy to open and operate on if any get damaged early since the entire robot is composed of attachable and detachable parts for easy replacement using joints. As we are implementing modular product concept it is relatively easy to refurbish the product as the part which is working alone could be taken out and the product could be refurbished.

- **Recycling of materials**

The brushes which are used for cleaning will be made of biodegradable and recyclable material, the body of the product is made up of aluminum which can be recycled and used again. Non recyclable parts like electronic components will be placed and interconnected in each component in such a manner that they can be removed, replaced or recycled.

- **Safer incineration**

The product is designed in such a way that the electrical, electronic and other components which have higher incineration cost can be removed so that they could be treated separately to the pollution and can be reduced to certain extent.

- **Taking in consideration local (informal) collection recycling systems**

The aluminium body of the robot can be easily recycled since many existing recyclable dumpyards exist. The metal obtained from the bot can be efficiently reused or recycled using existing facilities. Infinitely recyclable and highly durable, nearly 75 percent of all aluminum ever produced is still in use today. Aluminum is 100 percent recyclable and retains its properties indefinitely.
It is of utmost importance to recycle the E- waste generated by our product such as PCBs, processors and wires. The steps in e-waste recycling process are collection and transportation of the E-waste materials,shredding, sorting, and separation preparation for sale as recycled materials.

CONCLUSION

New to the world of Design and Product Development in the beginning, once identification of a problem had been done we had tried to come up with a novel solution after figuring out, understanding and identifying how an user indulges in the activity, logistical constraints and social factors in play and arrived at our final design. However we were unaware of the importance that environmental factors have on any product and sustainable design tools have helped in improving our initial product design.

Having been introduced to this century's UN goals, we explored the social, environmental and economic impact of our product and analysed the viability and success of our product. In the process we identified the materials and components we were planning on using and analysed its recyclability rates. On using an important Sustainable Design tool of Life Cycle Analysis which involves assessing the entire process from acquiring the raw material to it reaching our manufacturing plant and later transporting to our local warehouses that strategic positions and usage of local suppliers and transport providers reduced the overall environmental harm drastically.

Identifying the toxicity level of Aluminum on comparison with substitutes such as Steel and Composite Metal we arrived at a conclusion that though Aluminum was a lightweight material its toxicity levels and biodegradability rates were much higher than Steel that we have now altered the outer body material to Steel and reduced the material usage considerably to reduce the overall weight.
Large consumption of electricity for the cleaning process encouraged us to look for renewable sources of energy. Addition of solar panels for recharging the battery and to use it as a power source in times of need has reduced our consumption substantially and thereby reduced our carbon footprint.
Instead of using an external cooling system, to reduce the electricity consumption we have changed the internal design to channel the water drawn from the overhead tank via PVC pipes to our motors and finally to our brushes.
We have an identified biodegradable filter to improve the purity of the water used and have also provided a feature that treats the dirty water before its release to the water treatment plant or nearby water bodies.
After making the necessary modifications to our product, we analysed the impact of the product on the environment using the MET matrix where we found out how each and every process affects the environment and its toxicity level and in environmental impact assessment we found out 8 environmental indicators and found out how each process affects it.
Using swot analysis we found out our strength, weakness,opportunities and threats in the Cleaning Industry and in stakeholder analysis we found whether we were able to satisfy all the stakeholders needs and concerns.

Life cycle costing, or whole-life costing, is the process of estimating how much money you will spend on an asset over the course of its useful life. Whole-life costing covers an asset's costs from the time you purchase it to the time you get rid of it. Once logistics, transportation and acquiring of raw materials cost was taken into account, it was important to analyse the depreciation cost of these materials, the salvage cost we could make back by recycling and reusing the worn out product and the disposal cost of the non renewable resources. This extensive study has helped us come up with a good business model to break even within one and half years.
Though we are automating the process of window cleaning, we create equal employment and balance the employment opportunities destroyed. Since we use solar panels, the power dependency on the domestic power of the product decreases hence we are reducing the amount of fossil fuels burnt to produce electricity and we reduce deforestation. Since we treat the water after cleaning we reduce the pollution caused by us in that area and we are building an ecological park.

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