SMARTCLEAR

By

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Submitted in the partial fulfillment of the requirements
for the degree of Bachelor of Science in Design

At
Design Department
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College of Architecture and Design

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EFFAT UNIVERSITY
DESIGN DEPARTMENT

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate studies for acceptance a thesis entitled “Smart Clear” by Sarah Rabah in partial fulfillment of the requirement for the Degree of Bachelor of Science in Design.

Dated:

Readers: ______________________

EFFAT UNIVERSITY

AUTHOR: Sarah Rabah DATE: 2024

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DEPARTMENT OF COLLEGE: DESIGN

DEGREE: Product Design CONVOCATION: DEC YEAR: 2025

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Date: 4 November 2025

معهد البحوث والاستشارات
Research & Consultancy Institute

Notification of Research Ethics Approval

To whom it may concern

The Research Ethics Committee of Effat University and according to the University's Research Ethics Guidelines,
have decided to grant approval for the study as follows

Research team	Sarah Rabah
Decision number	RCI_REC/3.Dec.2024/7.1.Exp.22
Research title	Smart Clear
Duration of approval	One Academic Semester

The Research Ethics Committee have varied adherence of the following Principles:

- The research process will result no harm or discomfort for the participants.
- All precautions were taken to generate participants safety and rights are respected
- No harm will be generated to the used facilities.
- The information will be used by the research team for research purpose only.

Your cooperation is much appreciated,

Dean of Graduate Studies and

Research Prof. Mady A. Mohamed

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[3December 2024]

[Sara Rabah]

Dear Sarah Rabah

As the Chairperson of the Ethics Review Committee and according to the Effat University's Research Ethics Guidelines, we are pleased to inform you that your research entitled "***Smart Clear"*** has been approved. There is no indication that the research processes will result in any harm or discomfort for the participants. Furthermore, we are confident that you have taken all precautions to guarantee that participants are safe and their rights are respected.

The necessary 'informed consent forms' are prepared, thus all participants will be required to formally, through signing this form, indicate their consent to participating in this study. Participants will be given the opportunity to withdraw from the research at any time prior to the publication of the research findings. The matter of how data will be collected and stored, with reference to Data Protection legislation if relevant will be clarified for participants, with information being stored in locked cabinets or on IT hardware protected with the highest security software. The final thesis and possible significant elements of the project will be published and therefore openly accessible; however, no individual respondents will be identified or identifiable. The information provided by individual participants will not be made available to their employers or managers. Where key themes or ideas are drawn out, they will not be attributed to individuals. Similarly, individual case-study institutions or departments will not be named.

Yours Faithfully,

Dr Mady Mohammad

ACKNOWLEDGEMENT

We would like to take this opportunity and gratefully acknowledge all those who have assisted in making the SmartClear self-cleaning window system project a success.

First and foremost, let us begin with our special thanks to our project team: without their commitment, creativity, and teamwork, this novel idea would have never seen the light of day. Your hard work and commitment to excellence have been truly inspiring.

We wish also to thank our mentors and advisors for their invaluable guidance and expertise throughout the research process. Your insights and encouragement shaped our understanding and approach to this project.

We would also like to extend a special word of thanks to our survey and interview participants, who provided the feedback and perspective so helpful in assessing system effectiveness and user satisfaction. Your willingness to share your experiences greatly enriched our research.

We would also like to acknowledge our funding partners and sponsors, who believed in the dream enough to make the resources available to do this work.

Last but not least, to our loved ones-our families and friends-their ceaseless support and encouragement throughout the journey mean more than we can say. Your patience and understanding made it possible to focus on this undertaking.

I feel that together we have taken a very important step toward changing the face of window cleaning technology. We are excited about its reception in the market, and the impact it will have on the environment. Thanks, one and all, for your contribution to this project.

DEDICATION

This work is dedicated to all those who believe in the power of innovation as a means of creating a better world that is more sustainable.

To our families, who have been our bedrock with their relentless support and encouragement- thank you for the love and patience that have seen us through this process.

To our mentors and educators, who evoked the ability in us to think critically and question the status quo-your tutelage has been invaluable.

And to the future generations, may this work contribute to a cleaner, greener planet, inspiring further advancements in technology and sustainability.

We together strive for a brighter and more efficient tomorrow.

ABSTRACT

The SmartClear self-cleaning window system represents a novel approach to try to overcome some of the perennial problems of conventional window cleaning, especially for high-rise buildings and dusty areas. The present research provides an investigation of performance, environmental impact, and cost-effectiveness of SmartClear, a new generation of window glass that can clean itself by emulating the natural self-cleaning mechanism of the eyelid. SmartClear seeks to enhance safety and reduce the maintenance cost by taking out human labor, water, and chemical agents from the equation. Testing of the proposed system will be performed in a mixed-methods approach: quantitative performance metrics and qualitative user feedback targeting commercial property owners, homeowners, and sustainable architecture projects are expected to reveal its efficacy in maintaining cleanliness, contributing to environmental sustainability, and giving satisfaction to users. This research would further enlighten stakeholders and help position SmartClear in the market as a revolutionary, eco-friendly window cleaning solution.

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Chapter1: Introduction and Background of the Study

The product is positioned in NEOM’s The Line City is a prime example of a futuristic urban landscape, designed to minimize environmental impact while integrating advanced technologies. The Line features expansive glass façades, which will require efficient cleaning solutions that align with its sustainability goals. SmartClear addresses these needs by offering an autonomous system that reduces water and chemical use, requires minimal human intervention, and fits within the city’s smart technology infrastructure.

As automation continues to shape various industries, SmartClear leverages this trend, providing a hands-free, eco-friendly solution ideal for forward-thinking developments like The Line. This project will explore how the system can enhance operational efficiency and sustainability in large-scale, futuristic urban environments.

Figure 1.1 [SmartClear] [Ref: 20]

Introduction

The SmartClear self-cleaning window system marks a significant advancement in the realm of window maintenance technology, combining innovative design with a commitment to ecological sustainability. This groundbreaking system draws inspiration from nature, particularly the way eyelids are inherently equipped with the ability to self-clean, effectively maintaining clarity and hygiene. Recognizing the unique challenges posed by high-rise buildings and environments prone to dust and grime, SmartClear was developed to offer an autonomous solution to the persistent issues of window cleaning. Traditional methods often require extensive manpower and resources, not to mention the hazards associated with cleaning windows at great heights. SmartClear addresses these challenges head-on, providing a sophisticated and reliable alternative that not only enhances the aesthetics of tall structures but also reduces the environmental impact typically associated with window maintenance. By integrating advanced technology with nature-inspired principles, SmartClear not only simplifies the upkeep of windows but also contributes to the sustainability goals of modern architecture. This innovative system is poised to revolutionize how we think about window care, making it an essential solution for buildings in urban areas and dusty locales, ultimately promoting cleaner and more visually appealing environments.

1.1 Background of the Study

The challenges with cleaning in an urban environment are enormous: labor costs, safety concerns, and environmental impacts. Most methods of cleaning entail far too much water and chemical agents, contributing to environmental degradation. There is an urgent need for development that provides a sustainable, safe, efficient way of cleaning windows with minimal ecological footprint. This thus gives birth to SmartClear, an automated window cleaning system.

1.2 Problem Statement

Most of the window cleaning solutions in existence today are manual, labor-intensive, and dangerous, especially in high-rise buildings. The addition of water and other harmful chemicals further exacerbates the situation in terms of environmental impacts. Such problems are addressed through the provision of SmartClear with an automated, waterless, friendly-to-the-environment alternative with the potential to enhance safety while reducing the costs of maintenance.

Figure 1.2 [manual, labor-intensive, and dangerous, especially in high-rise buildings.] [Ref: 21]

Figure 1.3 [harmful chemicals] [Ref: 22]

Figure 1.4 [Water waste] [Ref: 23]

1.3 Research Objectives

1. The effectiveness of the SmartClear self-cleaning mechanism in removing different kinds of dirt and grime will be tested.
2. Compare SmartClear against other conventional methods of cleaning windows in terms of environmental impact.
3. Conduct cost-effectiveness and durability analyses over time for SmartClear.
4. Ascertain the level of user satisfaction with and acceptance of the product within the target audiences made up of commercial property owners, homeowners, and sustainable architecture projects.

1.4 Research Questions/Hypotheses

1. The SmartClear system is associated with what level of maintenance for window cleanliness compared to that of traditional methods?
2. What is the environmental impact associated with operating SmartClear as related to water and chemical use?
3. Is SmartClear cost-effective and durable when used over a long period of time?
4. How does user satisfaction of the SmartClear system rate across target demographics?

Methodology Overview

In this regard, the research will be carried out through a mix-methods approach, combining quantitative data collection-performance testing of the SmartClear system with qualitative interviews and surveys of potential users. Performance metrics include cleanliness level, energy consumption, and maintenance costs. User feedback will relate to satisfaction, usability, and benefits perceived.

1.5 Scope and Delimitation

The present study will limit itself to the performance of the SmartClear system in high-rise buildings and residential areas with a concentration on environmental and economic impact. The minor lacuna of this study could be the probable difference in user experiences depending on geographic locations and weather conditions, which may have an opposing effect on the mechanism performance.

Importance of the Study

The present study is important in the following ways:

- **The innovation of cleaning technology** will be helpful in developing independent cleaning systems, ensuring increased safety and efficiency for window maintenance.
- **Environmental Sustainability:** It addresses emerging demand for eco-friendly service provision in the construction and maintenance industry through the encouragement of cleaning without water and chemicals.
- **Market Potential:** The findings may be used to inform the design of products and marketing strategies associated with SmartClear, hence offering full potential towards targeted customer groups.

Audience for Which This Research Would Be Useful

1. Commercial Property Owners: Reduced costs and increased safety in maintaining windows.

2. House Owners: Ease in maintaining clean windows with no labour involvement.

3. Architects and Builders: Innovative, sustainable solutions for eco-sensitive projects.

4. Environmental Advocates: Understand better how sustainable technologies conserve water and minimize chemical usage.

1.6 Contribution and usefulness of the study

This study aims to thoroughly validate the efficacy and sustainability of the SmartClear self-cleaning window system, providing invaluable insights for investors, manufacturers, and consumers alike. By conducting comprehensive research, the study will offer robust evidence regarding the effectiveness of SmartClear as a novel window cleaning solution, highlighting its potential to revolutionize the market.

One of the key focuses of this research is to assess the practical performance of SmartClear in real-world applications. By examining its ability to maintain cleanliness and transparency over time, the study will establish its reliability as a cutting-edge alternative to traditional window cleaning methods. Additionally, the analysis will delve into the environmental benefits associated with the SmartClear system, such as reduced water usage and lower carbon emissions, aligning with global sustainability goals and highlighting the system's role in promoting eco-friendly practices.

Furthermore, the study will gather and present user feedback, evaluating satisfaction levels among those who have integrated SmartClear into their properties. By capturing user experiences and perceptions, the research will not only emphasize the functional advantages of the system but also identify any areas for improvement, ensuring that the product meets the diverse needs of its audience.

Ultimately, this comprehensive examination will provide critical information that can guide decision-making for stakeholders at all levels. Investors will gain insights into the market viability of SmartClear, while manufacturers will understand the product's performance characteristics and potential for scalability. Consumers, in turn, will receive evidence-based reassurance regarding the effectiveness and sustainability of the SmartClear system, empowering them to make informed choices in their pursuit of cleaner, more sustainable living environment.

Chapter2: Historical Background

Thesis Design for Product Designer: Historical Background of the project

This thesis explores the SmartClear self-cleaning window system, a revolutionary solution for urban cleaning. The system addresses air pollution, dust accumulation, and logistical challenges in high-rise buildings. The system offers a low-maintenance alternative to traditional cleaning methods and minimizes environmental impact. The development of SmartClear was informed by nanotechnology, surface coatings, and renewable energy sources. The thesis highlights the convergence of materials science and environmental engineering, highlighting the SmartClear system as an essential tool for modern urban living.

Figure 2.1 [Thesis Design for Product Designer] [Ref: 24]

Overview

Chapter No.1

- ✓ Introduction:
- ✓ Background of the study
- ✓ Statement of the Problem
- ✓ Objectives of the research
- ✓ Research questions/Hypotheses
- ✓ Summary of methodology
- ✓ Scope and Delimitation
- ✓ Significance of the Study
- ✓ Who will benefit from the study

  Contribution and Usefulness of the Study

Figure 2.2 [Introduction to Product Design] [Ref: 25]

2.1 Prehistoric Era

Primitive Tools:

Early humans used animal hides and natural brushes for cleaning, emphasizing functionality. SmartClear, designed with automated self-cleaning capabilities, mirrors these early tools. Stone and shell scrapers, made from sharp stones or shells, demonstrate early human creativity and precision.

Functional Aesthetics

Prehistoric tools' aesthetics were functional, with shapes and materials chosen for practicality. SmartClear, a minimalist design, combines functionality with visual appeal, blending with the environment to maintain visual harmony in modern buildings.

Adaptability

SmartClear is an eco-friendly, versatile system that adjusts to dirt levels, resembling early human adaptations, and uses natural elements for self-cleaning in various settings.

Figure 2.3 [Prehistoric Era] [Ref: 26]

2.2Ancient Civilizations

Egyptian Craftsmanship	**Greek Aesthetics**	**Roman Engineering**
SmartClear is a self-cleaning system that combines Egyptian craftsmanship with advanced technology, ensuring durability and longevity. Inspired by ancient Egyptian structures, it uses natural materials and adapts to various environmental conditions for cleaning.  **Figure 2.4 [Egyptian Craftsmanship] [Ref: 20]**	Greek aesthetics emphasize proportion, harmony, and symmetry, reflecting the Golden Ratio in architectural designs. SmartClear, a window maintenance system, combines these principles with functionality, incorporating natural light and ventilation, adapting to environmental conditions, and enhancing aesthetic values.  **Figure 2.5 [Greek Aesthetics] [Ref : 20]**	SmartClear, a system based on Roman engineering principles, uses high-performance glass for self-cleaning properties. It adapts to changing weather conditions, uses natural elements, and is designed for flexible installation in residential and commercial buildings. It also prioritizes sustainability.  **Figure 2.6 [Roman Engineering] [Ref: 20]**

2.3 Industrial Revolution

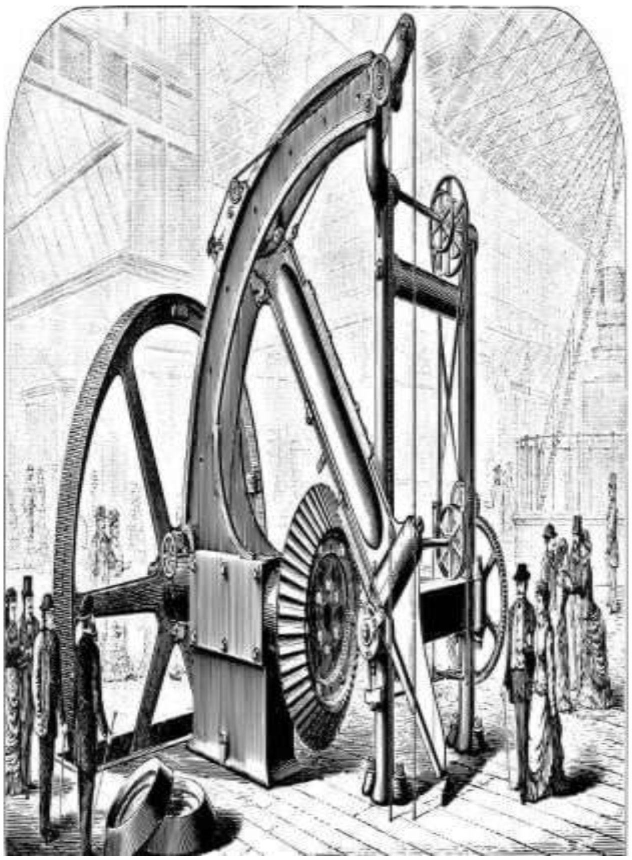

Figure 2.7 [Industrial Revolution] [Ref: 30]

Mass Production

The Industrial Revolution led to the development of advanced technologies like SmartClear, a self-cleaning window system that automates cleaning, freeing resources and labor. It uses advanced materials science and chemistry, is scalable, and adheres to quality control standards. SmartClear combines historical advances, promoting sustainability and resource efficiency, making it suitable for urban centers, skyscrapers, and high-rise apartments.

Technological Innovations

SmartClear, an industrial-inspired window system, utilizes sensor-driven technology to reduce manual cleaning, enhance efficiency, and provide uniform, cost-effective cleaning across diverse environments.

Transportation Design

The Industrial Revolution introduced innovations like SmartClear, a self-cleaning window system that automates cleaning, reduces manual labor, and enhances user experience, adapting to urban settings.

2.4 Modernism and 20th Century Design

Bauhaus Movement

SmartClear, a self-cleaning window system, combines Bauhaus principles with modernist design, addressing contemporary maintenance challenges and integrating art and technology.

Streamlined Aesthetics

SmartClear is a minimalist design system that blends clean lines and architectural styles, reducing clutter and fitting seamlessly into existing window frames. Its intuitive interface and high-performance glass enhance aesthetics, promote environmental consciousness, and create bright interiors.

Technological Influence

SmartClear is a self-cleaning window technology that uses nanotechnology, smart materials, and advanced sensor systems to enhance cleaning efficiency, reduce chemical use, and respond to environmental changes, extending glass lifespan and lowering maintenance costs.

Figure 2.8 [Modernism and 20th Century Design] [Ref: 31]

2.5 Contemporary Design and world war time

2.6 Sustainability	**2.7 User-Centric Approach**	**2.8 Digital Innovation**
SmartClear is a self-cleaning window system that combines modern design with sustainability, drawing inspiration from wartime innovations. Its advanced materials and coatings extend equipment lifespan, reduce water and chemical use, and enhance energy efficiency, demonstrating how technology can adapt to modern design and sustainability.	SmartClear is a modern, user-centric window cleaning system that combines modern design with wartime innovation, offering a hands-free, automated cleaning process suitable for residential and commercial use, reducing risks and saving time and costs.	SmartClear is a self-cleaning window system that uses digital sensors and IoT connectivity to track environmental factors, reduce energy use, and prolong glass life. It addresses sustainability by minimizing water and chemical use, conserving resources, and enhancing functionality and convenience.
 **Figure 2.9 [Sustainability] [Ref: 32]**	 **Figure 2.10 [User-Centric Approach] [Ref: 33]**	 **Figure 2.11 [Digital Innovation] [Ref: 34]**

2.9 Recent Developments and Trends

Artificial Intelligence

AI is revolutionizing industries like building maintenance and smart home technologies, with SmartClear utilizing AI sensors for data-driven insights, energy efficiency optimization, remote monitoring, and diagnostics.

Internet of Things

IoT is revolutionizing smart home products like SmartClear, enabling seamless communication, energy optimization, remote monitoring, user-centric features, security, and interoperability, enhancing efficiency and aesthetics.

Experiential design

Experiential design trends are transforming user interaction in products like SmartClear, enhancing user experience through interactive interfaces, sensory engagement, storytelling, environmental considerations, customization, and lifestyle integration.

Figure 2.12 [Artificial Intelligence] [Ref: 35]

Chapter Structure

Prehistoric Era

examines how the development of simple tools and survival items led to the beginning of product design.

Ancient Civilizations

investigates the highly developed design techniques used by ancient civilizations including Egypt, Greece, and Rome.

Middle Ages and Renaissance

explores the Renaissance's artistic expression and the development of design during the Middle Ages.

Industrial Revolution

examines how advances in technology and mass production have changed the way that products are designed.

Modernism and 20th Century

examines the significant aesthetic changes and design movements of the 20th century.

Contemporary Design

investigates the newest methods and trends in product design, such as digital innovation and sustainability.

Recent Developments

explores the latest advancements and possible directions in product design, such as the Internet of Things and artificial intelligence.

Chapter 3: Market Research

3.1 Introduction:

Chapter 2 provides a historical background for the SmartClear self-cleaning window system, tracing its development through various eras. It begins with the functionality of prehistoric tools and advances through the craftsmanship of ancient civilizations like Egypt, Greece, and Rome, emphasizing aesthetics and durability. The chapter explores the Middle Ages and Renaissance, highlighting innovations in glassmaking and the influence of artistic expression.

It then discusses the Industrial Revolution's impact on mass production and technological advances, leading to the automation seen in SmartClear. The chapter concludes with modern design principles, including sustainability and digital innovation, showcasing how historical context shapes contemporary product design and the necessity of SmartClear in urban environments.

This chapter explores the SmartClear self-cleaning window system through market research, comparative analysis, and product ergonomics and human factors. Market research identifies customer needs and trends, while comparative analysis evaluates product performance against competitors. Product ergonomics and human factors explore how design psychology impacts user experience. The chapter concludes with insights from market research and comparative analysis, focusing on the detailed design and technological specifications of the SmartClear system.

3.2 Market Research

Market research is the systematic process of gathering, analyzing, and interpreting information about a market, including information about the target audience, competitors, and industry trends. We conduct market research to understand customer needs, preferences, and behaviors, as well as to identify potential challenges and opportunities within the market. The benefits of market research include informed decision-making, enhanced product development, improved marketing strategies, and a competitive edge in the marketplace. By understanding market dynamics, businesses can tailor their offerings to better meet customer demands and stay ahead of competitors.

3.3 Competing Products

Here are 15 relevant products that compete with the SmartClear self-cleaning window system, along with their characteristics:

Product	Size	Color	Texture	Feature	Price
1. GleamPro Smart Window Cleaner 	12" x 6"	White and blue	Smooth plastic casing	Robotic, app-controlled, UV sterilization	$199
2. Hobot 198 Window Cleaning Robot 	11" x 11"	Black and silver	Plastic and rubber	Suction technology, remote control, automatic edge detection	$299

3. Ecovacs Winbot X 	12.4" x 12.4"	White	Smooth plastic	Cordless, smart navigation, two-way cleaning	$399
4. iRobot Braava Jet 240 	7.6" x 7.6"	White	Plastic	Mopping and sweeping, app connectivity	$199
5. Karcher WV 5 Plus N 	12.5" x 10.5"	Yellow and black	Plastic	Rechargeable, streak-free cleaning, removable tank	$129
6. Window Genie 	Varies by service	Service dependent	Service-based	Professional cleaning service, eco-friendly solutions	Varies
7. Squeegee Pro 	14" blade	Red	Rubber and plastic	Professional-grade squeegee, ergonomic handle	$29
8. NANOECO Nano Coating	Various package sizes	Clear	Liquid	Hydrophobic coating for self-cleaning	$49 per bottle

				effect	
9. H2O Mop X5 	7.5" cleanin g head	Blue	Plastic	Steam cleaning, multi-surface use	$99
10. Brilliant Smart Home Window Cleaner 	12" x 10"	Black	Smooth plastic	IoT connectiv ity, scheduled cleaning	$249
11. Zeblaze Smart Glass Cleaner 	15" x 5"	White	Plastic and rubber	Smart app control, automatic route mapping	$179
12. CleanSky Solar-Powered Window Cleaner 	12" x 12"	Green and black	Plastic	Solar-powered, environm entally friendly	$299

13. **Marvin Connected Home Automated Window System**. 	Customizable to fit various window dimensions.	The windows feature a modern, minimalistic design with narrow frames and are available in finishes that complement contemporary interiors.	The windows' texture enhances aesthetics and functionality, promoting energy efficiency, durability, and a clean, low-maintenance surface, aligning with SmartClear's eco-friendly objectives.	Windows feature automatic closing, flexible control modes like wall switches, mobile apps, and voice commands, enabling remote access and real-time monitoring.	Premium pricing aligns with its high-end materials and IoT functionalities
1. AquaBot Window Cleaning System 	15" x 15"	Blue	Durable plastic	Remote-controlled, customizable cleaning patterns	$349
2. SmartClean Pro 360 	14" x 14"	Black and white	Smooth plastic	360-degree rotation, voice control	$199

Table 1 **Competing Products**

3.4 Comparative Analysis

Comparative analysis is a method used to evaluate and compare products, services, or processes to understand their relative strengths and weaknesses. It involves identifying key features, specifications, and performance metrics across competing offerings in order to highlight differences and similarities. This analysis can be qualitative or quantitative and often utilizes matrices or tables for clarity.

Why Do We Conduct Comparative Analysis?

Comparative analysis helps businesses understand their market position, identify opportunities, and enhance product development. It helps identify gaps in the market, pinpoint unique features, and guide enhancements and innovations. By analyzing competitors, businesses can better meet customer needs and capitalize on market opportunities.

Benefits of Comparative Analysis

Comparative analysis aids strategic decision-making by providing a clear view of the competitive landscape, enabling better marketing, product features, pricing, and positioning. It also aids in benchmarking performance, improving marketing strategies, risk mitigation, and revealing customer preferences, thereby enhancing user experience and satisfaction.

Product	Features										
SmartClear Self-Cleaning Window System	Autonomous Self-Cleaning Mechanism	Eco-Friendly and Sustainable	**Integration with Smart City Infrastructure**	**Low Maintenance and Long Lifespan**	Energy Efficiency	Adaptable to Various Window Types	Weather-Responsive Cleaning	Real-Time Diagnostics and Predictive Maintenance	Aesthetic Design	Quiet Operation	Seamless Integration with Building Automation Systems
GleamPro Smart Window Cleaner	X	√	X	moderate	Moderate	√	X	X	moderate	√	X
Hobot 198 Window Cleaning Robot	√	√	X	√	√	√	X	X	Compact design -not as sleek	moderate	X
Ecovacs Winbot X	√	√	X	√	√	√	X	X	Modern design	√	X
iRobot Braava Jet 240	√	√	√	√	√	X	X	√	Compact and sleek	√	√
Karcher WV 5 Plus N	X	√	X	√	√	√	X	X	Functional-not sleek	√	X
Window Genie	X	√	X	X	X	√	X	X	X	X	X
Squeegee Pro	X	√	X	√	X	√	X	X	Simple and functional	√	X
NANO ECO	√	√	X	√	√	√	√	X	invisible	√	X

Nano Coating											
H2O Mop X5	X	√	X	√	Moderate, steam powered	X	X	X	Functional-not sleek	√	X
Brilliant Smart Home Window Cleaner	√	√	√	√	√	√	X	√	sleek	√	√
Zeblaze Smart Glass Cleaner	√	√	X	√	√	√	X	X	Functional-not sleek	√	X
CleanSky Solar-Powered Window Cleaner	√	√	X	√	√	√	√	X	modern	√	X
Marvin Connected Home Automated	X	√	X	√	√	√	X	X	√	√	√

Window System.											
AquaBot Window Cleaning System	√	√	X	√	√	√	X	X	functional	√	X
SmartClean Pro 360	√	√	√	√	√	√	X	√	√	√	√

Table 2 **Comparative Analysis**

Statement:

The SmartClear Self-Cleaning Window System outperforms many other products in its category due to its innovative combination of self-cleaning automation, energy efficiency, eco-friendliness, and seamless integration with both smart city infrastructure and building automation systems. Its adaptable design, predictive maintenance, and quiet operation further enhance its appeal, making it a superior choice for modern homes and commercial spaces. Unlike many competitors, which focus on specific aspects such as energy efficiency or low maintenance, SmartClear integrates all these elements into a cohesive system that delivers both reliability and user satisfaction. This holistic approach positions SmartClear as a leading solution for those seeking a truly intelligent window cleaning system.

Figure 3.1 [SmartClear] [Ref: 20]

3.5 Ergonomics and Design Psychology in SmartClear Self-Cleaning Window System

1. Ergonomics in SmartClear Design

SmartClear prioritizes ergonomics for its diverse user base in residential and commercial environments, including high-rise buildings, as it ensures comfort, efficiency, and safety.

Key ergonomic considerations for SmartClear:

- SmartClear automates window cleaning, reducing physical strain and user effort. Its intuitive interface, whether on a mobile app or remote control, simplifies installation and operation.
- The self-cleaning mechanism should be user-friendly, with large, comfortable buttons and an intuitive cleaning path algorithm, ensuring ease of use for users with limited dexterity.
- The system should have adjustable settings to adjust cleaning intensity based on dirt level and surface type, allowing users to switch between lighter and more intense cleaning.
- The SmartClear system should be ergonomically designed for easy maintenance, including easy access to refillable tanks and a fail-safe mechanism to prevent accidental malfunctions or over-reliance on the user.

2. Design Psychology in SmartClear Design

Design psychology studies how design elements impact user emotions, behavior, and decision-making. Understanding this is crucial for creating a positive user experience in SmartClear self-cleaning window system.

Key design psychology principles influencing SmartClear:

- The SmartClear product's design should be minimalist, clean, and unintrusive, blending seamlessly with modern home or office aesthetics, ensuring it becomes an invisible helper rather than a noticeable intrusion.
- The SmartClear system's visual appeal, featuring sleek lines and soft colors, aims to evoke positive emotions and convey sophistication, while its finish influences user perception of quality and reliability.

- SmartClear should incorporate a feedback mechanism to enhance user satisfaction and confidence, ensuring they feel progress and control over their cleaning cycle.

- Design psychology suggests users prefer simplified systems, and SmartClear should provide clear installation and operation instructions with color-coded indicators to boost trust and reduce anxiety.

- The product aims to enhance user engagement and connection through interactive elements like gentle sounds and haptic feedback, and a simple smartphone app with simple animations.

- SmartClear empowers users by allowing them to control and customize their window cleaning system through an app-based interface, enhancing their confidence in the process and ensuring efficient cleaning.

3. Incorporating Human Factors and Ergonomics into Design

The human factor significantly contributes to the intuitive and user-friendly nature of SmartClear.

- The cleaning system's design should consider the range of motion and reach, ensuring components are easily adjustable or extendable for different window heights in high-rise buildings.
- The system should be user-friendly, requiring minimal tools or complexity, and should provide clear, clear instructions without professional assistance, promoting ergonomic convenience.
- SmartClear should feature automatic adjustments for windows and weather conditions, reducing cognitive load by detecting cleaning cycle needs based on environmental factors like rain, pollution, or dust.

Conclusion

The SmartClear self-cleaning window system is a user-centered solution that combines advanced technology with ergonomic design. It offers a sleek, automated cleaning system that reduces the hassle of window maintenance. The system's user-friendly interface simplifies interactions and reduces stress associated with cleaning tasks. It's designed for both household and business environments, blending aesthetic appeal with functionality. The system addresses common user frustrations, promoting long-term satisfaction and reliability. It's a leading choice in sustainable and intelligent building solutions.

Analysis of SmartClear Self-Cleaning Window System

SmartClear is a revolutionary self-cleaning window system that combines innovative design with ecological sustainability, offering distinct advantages over traditional methods. Applying the 5Ws to its features and purpose strengthens its research statement and market position.

Who is SmartClear for?

SmartClear is an autonomous window cleaning system designed for urban environments with high-rise buildings and heavy dust accumulation. It caters to property owners, building managers, and homeowners, offering a reliable solution and eco-friendly alternatives.

What makes SmartClear different from existing products?

SmartClear is a self-cleaning window cleaner that uses natural eye mechanisms, energy efficiency, advanced materials, and smart technology like sensors and IoT connectivity.

When does SmartClear provide the most value?

SmartClear is a window cleaning system that eliminates scaffolding and ladders in high-rise buildings, saving time and labor costs, and can be programmed for regular cleaning.

Where will SmartClear be used most effectively?

SmartClear is ideal for high-rise buildings, commercial spaces, skyscrapers, and urban residential homes due to pollution, dust, and weather conditions. It integrates with smart home systems and can be adapted for warehouses or public buildings with large glass expanses.

Why is SmartClear important for today's market?

SmartClear is a sustainable, eco-friendly window cleaning solution, aligning with the growing demand for autonomous robotic solutions in smart homes and IoT integration.

Strengthening the Research Statement

SmartClear is a sustainable, user-centric window cleaning solution that combines advanced automation and self-cleaning mechanisms, addressing frequent cleaning needs in hard-to-reach areas, a response to growing urbanization and environmental consciousness.

Chapter 4: Implementation and Testing

4.1 Introduction

Chapter 4 goes deeper into understanding the users, building on the market research and comparative analysis conducted in Chapter 3, where we discovered rival products, consumer needs, and the unique features of the SmartClear self-cleaning window system. In order to identify preferences, behaviors, and pain points, this chapter uses user research approaches to examine target groups and personas. Designing user-centered solutions that improve SmartClear's functionality and attractiveness is based on insights obtained from qualitative and quantitative research approaches.

This chapter uses the 5Ws (who, what, when, where, and why) to answer important questions through focus groups, surveys, interviews, expert consultations, and observations. We link research findings with practical design insights by identifying different user types and developing comprehensive personas, which direct the creation of SmartClear's features and user experience.

4.2 Methods for User Research

4.3 Qualitative Research

focuses on using open-ended research to comprehend users' requirements, experiences, and motivations.

Methods and Applications:

1. **Interviews**

    Who: Current property owners, building managers, and tech-savvy homeowners.

    What: Insights into window cleaning habits, challenges, and preferences.

    When: Conducted during initial research phases to define user requirements.

    Where: Online or in-person interviews for accessibility.

    Why: To uncover unmet needs and frustrations related to window cleaning.

2. **Key Questions**:

    What challenges do you face with your current window cleaning methods?

    What features would make a window cleaning system ideal for you?

   Findings: Traditional approaches are frequently viewed by users as time-consuming, risky, and boring. Residents of high-rise buildings place a high value on automation and security.

Interview 1:

Participant: Huda, house wife, 2-story house

What challenges do you face with your current window cleaning methods?

Huda: "I use a mop and bucket for my routine cleaning, but it's incredibly exhausting, especially for the second-story windows that are higher up. Because I'm afraid of falling and it feels unsafe, I dislike using ladders. Even though I'm constantly mindful of keeping things safe and non-toxic because I have small children, I still find it difficult to get the windows spotless without leaving stains."

What features would make a window cleaning system ideal for you?

Huda: "I like a ladder-free system that is simple for me to use. Perhaps a robotic system that could clean the second-story windows automatically or an extending pole. In order to move it around the house with ease, I would like it to be lightweight and portable. It must also be safe for my children; an eco-friendly and non-toxic product would be ideal."

Interview 2:

Participant: Salma, stay-at-home mom, small single-story house

What challenges do you face with your current window cleaning methods?

Salma: "Even though I don't have many windows, the ones I do have get filthy quite easily, especially when it rains. The dirt always seems to smear rather than come off, even though I usually use a cloth and a spray cleaner. I can never manage to get the windows to be fully streak-free, which is worsening. Additionally, it takes time away from other tasks, and occasionally I simply lack the energy."

What features would make a window cleaning system ideal for you?

Salma: "Having a tool that doesn't require a lot of cleaning would be fantastic. Something that could effectively and swiftly clean windows without leaving streaks would be fantastic. Perhaps a device that works like a vacuum and can simultaneously remove moisture and dirt so I don't have to keep wiping. It would be even better if it were lightweight enough for me to take around and store with ease.

Interview 3:

Participant: Sarah, stay-at-home mom, lives in a flat (3rd floor)

What challenges do you face with your current window cleaning methods?

Sarah: “When it comes to window washing, living in an apartments presents a unique set of difficulties. My main issue is that I have to step out onto the balcony to reach the outside of my windows, and I don't feel safe leaning out there to clean. A step ladder isn't strong enough for me to feel secure, despite my attempts to use it. Additionally, I've discovered that streak-free windows aren't necessarily the result of conventional cleaning techniques like wiping with a cloth and cleaning solution. Because of all the dust and smudges from the city, I frequently have to clean them more than once, which is incredibly annoying.”

What features would make a window cleaning system ideal for you?

Sarah: "I believe that a method that enables me to safely clean the outside windows is what I need most. Without having to step outside onto the balcony, I would want something that could reach the outside of the apartment. Perhaps it would be ideal to have a cleaning head on an extending pole that could reach the entire height of the window from inside the apartment. In order for me to clean quickly, it would also need to be lightweight and manageable. It's also crucial that it doesn't leave streaks on the windows and that it functions properly despite the humid weather we have here. As long as it is safe for my windows, an automated system perhaps a robotic cleaner that I could install would be fantastic, and doesn't require a lot of storage space when not in use."

Interview 4:

Participant: Ebtissam, stay-at-home mom, lives in a flat (4th floor)

What challenges do you face with your current window cleaning methods?
Ebtissam: Cleaning the exterior of my windows is particularly difficult for me because I live on the fourth floor. The outdoors requires me to use a long pole or lean out from the balcony, both of which I find dangerous, but I can handle the inside. I've tried using a long-handled window cleaning tool, but I find it rather difficult to use and never seem to get the corners or edges right. In addition, the city's dust and filth are a recurring issue for me, and the cleaning agents I've employed frequently leave behind streaks that I have to repeatedly remove."

What features would make a window cleaning system ideal for you?
Ebtissam: "I need something that makes it safer and easier to clean the exterior of my windows. To avoid having to bend over the balcony to access the windows, it would be perfect if I could use a tool with an extension pole from within the apartment. If it had a revolving head or anything that would allow me to reach the window's edges without straining, I would adore it. Considering the outside pollution, it should also leave the windows streak free. I wouldn't have to worry about tangled cables if I had a cordless option. It would be fantastic if there was a robotic option that could clean the window on its own by going outside! Since my apartment doesn't have much additional space for large equipment, all I would want is something that's portable and easy to store."

Findings:

The study reveals common challenges faced by housewives in cleaning windows, including difficulty reaching exterior windows, time and effort required for cleaning, and the issue of streaks. Safety concerns were also highlighted, especially when accessing hard-to-reach areas.

The most desired features in an ideal window cleaning system include ladder-free and reachability, lightweight and portable, streak-free cleaning, automated or robotic cleaning, cordless options, and eco-friendly and non-toxic products. Participants expressed a preference for tools that can be used from within the home, eliminating the need for ladders or leaning out from balconies.

Efficient and time-saving methods were also highly valued, with systems that could clean quickly, leave windows streak-free, and require minimal physical effort. Convenience and portability were also important, particularly for those with limited storage space.

The overall goal is to simplify the window cleaning process, making it safer, faster, and more effective while being mindful of storage constraints and environmental impact. The most preferred features include extendable poles, robotic cleaners, cordless designs, and eco-friendly materials.

In conclusion, the ideal window cleaning system for housewives living in flats or two-story houses should focus on safety, ease of use, and efficiency. The ability to clean hard-to-reach windows without ladders, leaving them streak-free, and requiring minimal physical effort is paramount.

3. **Focus Groups**

Who: Groups of 6–8 individuals from various user demographics.

What: Discussions to explore opinions on prototype designs and concepts.

When: During mid-research phases to validate design ideas.

Where: Moderated sessions in co-working spaces or virtually.

Why: To generate feedback on initial designs and identify common themes.

Findings: Consumers value low maintenance costs and environmentally beneficial solutions, but they also want user-friendly instructions and window type adjustability.

4.4 Quantitative Research

focuses on statistical insights to evaluate user preferences and validate assumptions.

Methods and Applications:

1. **Surveys**

Who: A broad audience, including urban homeowners and property managers.

What: Gather preferences on features like automation, energy efficiency, and price range.

When: Distributed at various research stages to measure demand.

Where: Online platforms like Google Forms or Typeform.

Why: To validate hypotheses and prioritize features.

Key Findings:

85% prefer automated cleaning systems for safety.

70% prioritize energy efficiency over aesthetic design.

2. **Observation**

Who: Users interacting with current cleaning solutions.

What: Observe behaviors and challenges.

When: Conducted alongside interviews for real-time insights.

Where: In residential or commercial buildings.

Why: To understand real-world application barriers.

Key Findings: Users frequently leave windows half cleaned because they have trouble reaching hard-to-reach locations.

4.5 Expert Interviews

discussions with sustainability specialists, building managers, and architects to learn about integration issues and market trends.

Key Questions:

What are the current trends in automated building solutions?

How can SmartClear align with smart city objectives?

Findings: It is crucial to integrate with IoT systems. Experts advise emphasizing ease of maintenance and longevity.

4.6 Personas

According to studies, different user groups are represented by the following personas:

The Urban Professional

Demographics: Age 30–45, lives in high-rise apartments, busy lifestyle.

Needs: Automation, energy efficiency, low maintenance.

Pain Points: Limited time for cleaning, safety concerns.

Goals: Reliable, eco-friendly cleaning solutions integrated with smart home systems.

The Building Manager

Demographics: Age 40–55, manages commercial buildings or complexes.

Needs: Cost-effective, scalable solutions for multiple windows.

Pain Points: High maintenance costs, labor risks.

Goals: Improve tenant satisfaction and reduce operational costs.

The Tech Enthusiast

Demographics: Age 25–35, early adopter of IoT devices, resides in smart homes.

Needs: Advanced features, app integration, energy monitoring.

Pain Points: Limited compatibility with other systems.

Goals: Seamless integration with existing tech.

The Eco-Conscious Consumer

Demographics: Age 35–50, prioritizes sustainability, owns residential properties.

Needs: Energy-efficient, eco-friendly solutions.

Pain Points: Products that lack eco-certifications.

Goals: Reduce carbon footprint without compromising quality.

Conclusion

We have developed personas and conducted extensive research, which has given us important insights into the varied demands and preferences of our target audience. These results highlight how crucial it is to give automation, environmental friendliness, and intelligent, smooth integration top priority when designing products. Understanding the unique needs of different user groups, from property managers of big commercial spaces to busy urban workers, will help us make sure that SmartClear is not merely a technology innovation but also a useful, user-centric solution. We can solve particular issues like accessibility, upkeep difficulties, and environmental sustainability thanks to this better understanding, making SmartClear a product that is innovative, flexible, and ready for the market. In the end, by conforming to our users' beliefs and expectations, we establish SmartClear as a highly competitive and appropriate solution in a constantly changing marketplace, able to precisely and efficiently address a variety of demands by aligning with the values and expectations of our users.

Chapter5: Results and Discussion

5.1 Introduction:

In the previous chapter, we focused on gathering valuable insights through a combination of focus groups, surveys, interviews, expert consultations, and observations. By utilizing the 5Ws (who, what, when, where, and why), we addressed key questions and linked these findings to practical design decisions, resulting in the creation of user personas. These personas informed the development of SmartClear's features and user experience. In this chapter, we will explore the role of case studies in the design process, examining their use in providing evidence-based inspiration. A case study is an in-depth analysis of a product or solution, used to understand its successes, challenges, and key elements. Case studies are typically used at various stages of the design process to draw comparisons and extract best practices. We use them to learn from existing products, identifying what worked and why, which can help inform the development of a new solution. In this chapter, we will look at three successful products within each relevant domain, analyzing their individual components, functions, and design strategies. By comparing these case studies, we aim to identify the best practices to adopt, while also highlighting areas where our product can break new ground and offer a unique, innovative solution.

5.2 What is a Case Study?

A case study is a comprehensive, close look at a product, project, or phenomenon in realistic, natural settings. It normally focuses on an analysis of design, functionality, interaction with users, problems faced, and results regarding the case. Regarding product development, case studies let one understand how some given product or solution was conceptualized and developed, and received by a user or customer. These might include review market response, technical performance, and lessons learned throughout the life cycle.

These case studies allow conceptual understanding and theories to come out clearly, provide design principles, and panoramic views about successes or challenges faced by real products or solutions.

5.3 How and Why We Use Case Studies?

Case studies are among the most feasible design tools for the following reasons:

1. Learning from Real-World Examples: Case studies allow designers to learn from existing solutions and spot patterns, successful design elements, and areas of failure. We can see how other products have behaved in the market and implement that knowledge in order not to fall into the same traps and repeat strategies that worked.

2. Fact-based inspiration: During the generation of new products, one must draw inspirations based on facts rather than assumptions and mere thoughts. Case studies inspire-actually, through evidence as to what really works and why end in the generation of new ideas or refinement of existing ones.

3. Identification of Best Practices: Where there is more than one case study, the best practices that may lead to the success of a product can be identified. These may include user centered design, sustainability effort, and effective branding strategies. These best practices could then be adopted or adapted according to the needs of the new product.

4. Case studies allow the identification of opportunities to innovate, since they also indicate where the market has shortcomings with regard to certain product offerings. It is from such insights that the opportunity to innovate both at a functional, design, or user experience levels will be availed for the new product to be differentiated and meet customers unmet needs.

5. Reduction of Risks: Case studies also help to reduce risks, showing design flaws or technical limitations, as well as factors of market refusal, which the new product will try to avoid in such a way that it cannot fall into similar mistakes along its journey. This saves money, time, and effort.

6. Benchmarking: Case studies provide a means to benchmark against industry leaders or competitors and help position the new product effectively in the market. Analyzing competitors allows a company to creat

e differentiating features or find ways to outperform existing solutions.

5.4 Relevance of Case Studies with My Research

Case studies, in the context of SmartClear, a high-tech, eco-friendly, autonomous window cleaning solution, are relevant for several reasons:

1. Design Inspiration: SmartClear aims to innovate in the window cleaning market. Reviewing case studies of successful cleaning robots, automation systems, and eco-friendly technologies can provide insights into how to integrate AI, solar power, and adaptive sensors effectively. Case studies of robotic systems, such as the window cleaning robots by companies like Ecovacs and Windowmate, can reveal strengths and weaknesses of current solutions, offering valuable lessons in terms of functionality, durability, and efficiency.

2. User Experience and Personas: We need to consider case studies of user-centric design in similar autonomous cleaning products to make sure that SmartClear is suitable and desirable for our target users, including high-rise building owners, property managers, and businesses concerned about the environment. The user feedback of the earlier products can reveal some of the common pain points and therefore be used in designing SmartClear with more seamless intuitive use.

3. Market Positioning: Case studies of similar products, such as solar-powered or AI-driven window cleaning systems, will help SmartClear understand the gaps in the market. By analyzing how existing products have been marketed, we can establish a USP for SmartClear that emphasizes eco-friendly and autonomous features while offering practical solutions for building maintenance.

4. Challenges and Risk Management: Case studies of high-tech cleaning solutions will highlight common challenges faced by companies, including technical limitations, maintenance issues, or user complaints. These can serve as a learning point for SmartClear to be designed with strong features that minimize the risk of failure, especially in high-rise environments where safety and durability are key.

5. Sustainability and Innovation: Sustainability sells, and case studies in solar-powered or eco-conscious technologies could serve as inspirations for better energy efficiency and sustainability practices for SmartClear. For example, case studies in solar-powered robotics or biomimicry in technology could give ideas regarding integrating more sustainable solutions into SmartClear.

5.5 Case Study 1 – External Shape – Form

Figure 5.1 [IPC Eagle High Rise 3M10] [Ref: 36]

IPC Eagle High Rise 3M10 Self-Climbing Window Cleaning System

This robotic system is designed for high-rise buildings, featuring a self-climbing mechanism that autonomously cleans windows. Its compact and streamlined form allows it to navigate building exteriors efficiently. Problem analysis1?? Material analysis1? Size analysis1? Evaluation1-2?

Figure 5.2 [Sky Pro Mini High Rise 80-Inch] [Ref:37]

Sky Pro Mini High Rise 80-Inch Self-Climbing Robotic Window Cleaner

Engineered for high-rise applications, this device utilizes thruster fans to adhere to glass surfaces, ensuring thorough cleaning. Its design emphasizes safety and efficiency in challenging environments.

Figure 5.3 [HOBOT 298] [Ref: 38]

HOBOT 298 Window Cleaning Robot

A compact, square-shaped robot that attaches to windows via suction. It features an automatic water spray and AI technology to navigate and clean glass surfaces effectively.

Figure 5.4 [AlfaBot X7] [Ref: 39]

AlfaBot X7 Smart Window Vacuum Cleaner

This device combines vacuum suction with an automatic water spray system, allowing it to clean both interior and exterior windows. Its ergonomic design facilitates easy handling and operation.

Introduction: Design Problem

Project Information:

`The SmartClear self-cleaning window system is an innovative solution designed to automate window cleaning for high-rise buildings and dusty environments. Its biomimetic approach, inspired by the natural self-cleaning mechanism of eyelids, offers a sustainable and efficient alternative to traditional window maintenance.

The Problem:

Traditional window cleaning methods for high-rise buildings are labor-intensive, risky, and resource-heavy. SmartClear seeks to solve this problem by developing a system that ensures clean windows with minimal human intervention, reducing costs, improving safety, and contributing to environmental sustainability.

Problem Analysis

To achieve the self-cleaning function, the following components are necessary:

Cleaning Mechanism: Rotating or oscillating brushes, wipers, or microfiber pads.

Water Dispensing System: Controlled jets or spray nozzles to apply cleaning solution or water.

Sensors and AI Integration: Sensors to detect dirt levels, weather conditions, and operational efficiency.

Power Source: Solar panels or a direct power connection for sustainable operation.

Control Unit: A central processing system to manage operations autonomously.

Visuals: Include annotated images of similar existing products like robotic window cleaners, wiper systems, or brush mechanisms.

Materials Analysis

Materials needed to achieve function and durability:

Glass: High-strength tempered glass with hydrophobic coating for improved dirt resistance.

Silicone/Rubber: For flexible wipers or seals ensuring smooth operation without scratches.

Plastic (ABS/PC): Lightweight and durable for external housing and protective components.

Metal (Aluminum/Steel): For structural support and components of the cleaning mechanism.

Electronics: Advanced circuitry for sensors, motor drives, and AI systems.

Size Analysis

Typical dimensions and scaling considerations:

Cleaning unit size: ~30cm x 20cm x 10cm for compactness on high-rise windows.

Track or attachment systems: Customized to fit standard commercial and residential window sizes (e.g., 1m x 2m or larger).

This analysis ensures compatibility with various building designs while maintaining efficiency.

Evaluation

Lessons Learned:

A compact, aerodynamic design is ideal for reducing wind resistance and ensuring smooth operation.

Durable materials like tempered glass and hydrophobic coatings enhance longevity.

Autonomous features powered by solar energy promote sustainability.

How to Apply:

The insights gained will guide the development of SmartClear's streamlined design. Materials and technologies like hydrophobic coatings, flexible wipers, and efficient AI integration will ensure the product is lightweight, eco-friendly, and highly functional.

5.6 Case study 1.1 – Design language

1. Dyson Airblade Hand Dryer

Design Language/Inspiration:

Minimalist, sleek, and functional, with an emphasis on clean lines and high-tech materials. Inspired by engineering efficiency and modern architecture.

Characteristics:

Emphasis on form following function.

Aerodynamic design for optimized performance.

Durable and recyclable materials (e.g., ABS plastic).

Adoption Methodology:

Apply a minimalist and futuristic aesthetic to the SmartClear system, focusing on user-friendly integration into modern high-rise architecture. Use lightweight, durable materials like aluminum or tempered glass for the casing.

2. Tesla Powerwall

Design Language/Inspiration:

Modern and futuristic, inspired by clean energy and cutting-edge technology.

Characteristics:

Smooth, curved edges.

Uniform, neutral color palette (e.g., white, silver, or matte black).

Compact, wall-mounted design for seamless integration into homes or businesses.

Adoption Methodology:

Consider a sleek, compact design for the SmartClear system's external components. Integrate into the building's structure to make it visually unobtrusive while emphasizing eco-friendly technology.

3. Roomba Robotic Vacuum Cleaner

Design Language/Inspiration:

Biomimetic and adaptive, focusing on automated problem-solving in confined spaces.

Characteristics:

Rounded, compact, and ergonomic shape.

Adaptive sensors for intelligent navigation.

Quiet operation, ensuring minimal disturbance.

Adoption Methodology:

Emulate the Roomba’s compact and adaptive features. Design the SmartClear system to intelligently detect window size, shape, and dirt level, ensuring efficient and customizable cleaning.

Lotus Effect in Coatings

Design Language/Inspiration:

Biomimicry of the lotus leaf’s natural self-cleaning properties.

Characteristics:

Surface coating with nano-structures that repel dirt and water.

Invisible but highly effective.

Associated with nature-inspired, sustainable innovation.

Adoption Methodology:

Leverage biomimicry to develop a SmartClear coating that enhances self-cleaning efficiency. Highlight this feature in marketing and design through nature-inspired visuals, such as wave or /leaf patterns.

Synthesis for SmartClear Design:

Combining these inspirations, Smart Clear may embody:

A modern, futuristic aesthetic with smooth curves and clean lines, ensuring seamless integration into building designs.

Compact and adaptive components with intelligent systems for automated, customizable cleaning.

A focus on sustainability and biomimicry, using materials and coatings inspired by nature to ensure both functionality and environmental harmony.

User-centric technology, emphasizing ease of use, durability, and quiet operation to appeal to both businesses and homeowners.

5.7 Case study 2 - Product size (4 most popular/successful products images that share similarities

Hobot 298

Description: A robotic window cleaner equipped with ultrasonic water spray technology that converts water into a fine mist for streak-free cleaning. It uses AI for efficient cleaning paths and features edge detection, making it suitable for frameless windows.

Size: Compact and lightweight at approximately 24 x 24 cm.

Image:

Figure 5.5 [Hobot 298] [Ref: 40]

Ecovacs Winbot X

Description: A cordless robotic window cleaner with safety tethering for high-rise windows. It autonomously navigates using advanced sensors to provide a complete clean.

Size: Dimensions typically range around 28 x 28 cm.

Image:

Figure 5.6 [Ecovacs Winbot X] [Ref: 41]

AlfaBot X7

Description: Known for its quiet operation and dual cleaning modes. It features intelligent path planning and microfiber pads for deep cleaning.

Size: Compact, suitable for standard and large windows.

- **Image**:

Figure 5.7 [AlfaBot X7] [Ref: 39]

2. **Mamibot W120-T**
    - **Description**: A budget-friendly option with suction technology for secure operation. It includes an app-based remote control and automated cleaning routes.
    - **Size**: Small, lightweight, approximately 23 x 23 cm.

- **Image**:

Figure 5.8 [Mamibot W120-T]   [Ref: 42]

5.8 Case study 3 – Functions (4 most popular/successful products images that share similarities)

1. Hobot 298

Figure 5.9 [Hobot 298]   [Ref: 40]

Function Analysis:

Achieves cleaning via ultrasonic water spray and AI-guided navigation.

Equipped with powerful vacuum suction to secure itself on glass surfaces.

Uses edge detection to clean frameless windows effectively.

Controlled via Bluetooth or remote control.

Components:

Ultrasonic water spray system.

High-density microfiber pads.

Vacuum motor for adherence.

Sensors for navigation and edge detection.

Evaluation:

The ultrasonic spray can inspire an eco-friendly cleaning mechanism.

Compact size and edge detection are ideal for versatile application.

2. Ecovacs Winbot X

Figure 5.10 [Ecovacs Winbot X] [Ref: 41]

Function Analysis:

Focuses on safety with tethering for high-rise windows.

Autonomous navigation using advanced sensors.

Includes app-based controls for ease of use.

Components:

Secure suction system.

Safety tether for high-rise usage.

Sensors for intelligent navigation and edge detection.

Microfiber pads for cleaning.

Evaluation:

Safety-focused design offers a unique perspective for high-risk applications.

Advanced sensors can inspire path optimization for new designs.

AlfaBot X7

Figure 5.11 [AlfaBot X7] [Ref: 39]

- **Function Analysis**:
  - Dual cleaning modes for different surfaces.
  - Intelligent path planning for efficient cleaning.
  - Quiet operation enhances user experience.
  -
- **Components**:
  - Dual microfiber pads.
  - Intelligent navigation sensors.
  - App or manual controls.
- **Evaluation**:
  - Focus on noise reduction is beneficial for residential use.
  - Dual modes could be adapted for multipurpose cleaning systems.

3. **Mamibot W120-T**

Figure 5.12 [Mamibot W120-T] [Ref: 42]

- **Function Analysis**:
  - Budget-friendly yet efficient.
  - Uses suction technology for secure cleaning.
  - Includes an app for remote operation.
- **Components**:
  - Suction motor.
  - Navigation sensors.
  - Replaceable microfiber pads.
- **Evaluation**:
  - Cost-effectiveness offers an avenue for affordable solutions.
  - Suction and compact size provide a balance of performance and portability.

5.9 Case study 4 - Materials (4 most popular/successful products images that share similarities)

1. **Hobot 298**

Figure 5.13 [Hobot 298] [Ref: 40]

Materials:

Body: Durable plastic housing.

Pads: Microfiber for streak-free cleaning.

Internal Components: Precision-engineered electronics and motors.

Ecovacs Winbot X

Figure 5.14 [Ecovacs Winbot X] [Ref: 41]

Materials:

Housing: Lightweight yet robust plastic.

Pads: Microfiber with high absorbency.

Safety Rope: High-tensile material.

2. AlfaBot X7

Figure 5.15 [AlfaBot X7] [Ref: 39]

Materials:

Body: Plastic composite for durability and lightweight.

Pads: Replaceable microfiber for deep cleaning.

Internal Components: Silent motor technology.

Mamibot W120-T

Figure 5.16 [Mamibot W120-T] [Ref: 42]

Materials:

Lightweight plastic casing.

Microfiber cleaning pads.

Precision-engineered suction motor.

5.10 Case study 5 - Textures and aesthetic features (4 most popular/successful products images that share similarities)

Texture and Aesthetic Features:

Hobot 298:

Figure 5.17 [Hobot 298] [Ref: 40]

Features a compact, square design with clean lines suitable for modern interiors.

Comes with a neutral color scheme (white and grey) to blend seamlessly into home or office environments.

Uses microfiber cleaning cloths with a fine texture to ensure effective cleaning without scratching surfaces

The AlfaBot X7

Figure 5.18 [AlfaBot X7] [Ref: 39]

Has a sleek, modern design focused on functionality and durability.

Its exterior is made of sturdy, lightweight materials with a minimalist aesthetic.

It features soft microfiber cleaning pads designed for optimal dirt trapping, complemented by high-performance suction to maintain adherence to glass surfaces.

The soft pads, combined with smooth plastic housing, ensure scratch-free operation, and the device is visually appealing with clean lines and a neutral color palette.

The design also integrates an ergonomic grip and intuitive interface for ease of use.

Ecovacs Winbot X:

Figure 5.19 [Ecovacs Winbot X] [Ref: 41]

Compact with a white matte finish, making it visually appealing and less prone to showing fingerprints.

Designed with a textured grip surface for easy handling, complemented by a futuristic LED display for status updates.

Rounded corners and a minimalistic design focus enhance its contemporary vibe

Mamibot W120-T

Figure 5.20 [Mamibot W120-T] [Ref: 42]

The cleaning pads are made of soft, reusable microfiber material designed for effective cleaning and longevity.

The outer casing is smooth with a glossy finish, giving it a polished and futuristic look.

The device includes strategically placed non-slip rubber elements to ensure safe operation, especially on high-rise surfaces.

Available in neutral colors like white and black, the aesthetic aligns with a contemporary design style, fitting seamlessly into modern homes

5.11 Case study 6, 7, 8… - Based on your product and details it requires, add more; for your benefit

Case Study 6: Adaptive Cleaning Technologies

Inspiration: Adaptive cruise control in modern vehicles.

Key Features:

Uses sensors to detect the environment and adjust performance dynamically.

AI-driven decision-making for safety and efficiency.

Low-energy consumption for extended usage.

Application for SmartClear:

Integrate adaptive sensors to adjust cleaning intensity based on dirt level, weather conditions, or window material. For example, dusty environments may trigger a higher cleaning frequency, while rainy weather might initiate a protective mode.

Case Study 9: Autonomous Robots for Hazardous Environments

Inspiration: Boston Dynamics' Spot robot and underwater cleaning drones.

Key Features:

Autonomous navigation and task execution in challenging or dangerous environments.

Rugged design to withstand harsh conditions.

Remote monitoring and control for user convenience.

Application for SmartClear:

Develop the system to function autonomously in extreme conditions, such as sandstorms or freezing temperatures, commonly faced by high-rise buildings. Remote control options via a mobile app would add to user convenience and safety.

5.12 Final Evaluation

The insights from these products demonstrate the importance of compactness, material efficiency, and multifunctionality. Incorporating AI-guided navigation, edge detection, and eco-friendly cleaning mechanisms can enhance the new product's design. The use of durable and lightweight materials like plastic composites and microfiber pads ensures functionality and user-friendliness while maintaining affordability.

Chapter 6: Product design specification

6.1 Product Positioning: Define Your Product's Market Position

SmartClear's market position targets high-rise building owners, property managers, and environmentally conscious businesses seeking an efficient, safe, and sustainable window cleaning solution. SmartClear stands as an alternative to traditional cleaning methods by addressing critical inefficiencies and environmental impacts.

Key Selling Points:

Autonomous and Sustainable Cleaning: Operates with minimal human intervention, powered by solar energy, and inspired by biomimicry to emulate the eyelid's natural cleaning mechanism.

Eco-Friendly Design: Eliminates chemical use and minimizes water waste, aligning with sustainability goals.

User-Centric Innovation: Features AI technology, advanced sensors, and adaptive cleaning mechanisms for seamless integration and effective operation.

Safety and Durability: Designed for high-rise applications with robust materials, ensuring minimal maintenance and enhanced user safety.

Market Gap Fulfillment: SmartClear bridges gaps identified in Chapter 3 by offering:

Cost-Effectiveness: Reduces long-term operational costs through energy-efficient features and minimal labor requirements.

Enhanced Safety: Eliminates the risks associated with manual cleaning of high-rise buildings.

Customizable Features: Adapts to various window types and integrates with modern architectural designs, including smart buildings.

SmartClear positions itself as the innovative solution for urban environments, addressing frequent cleaning needs in dusty or polluted areas while contributing to sustainable development goals.

6.2 Product Design Brief & Specification: Translate Customer Needs into Technical Requirements

User Needs:

Efficiency: Automated and fast operation to save time and labor.

Safety: Reliable performance in high-rise environments with safety-enhancing features.

Sustainability: Eco-friendly operation that minimizes energy and resource consumption.

Ease of Use: Simple installation, intuitive operation, and remote control.

Durability: Designed to endure extreme weather conditions like strong winds and dust storms.

Technical Specifications:

Dimensions: Compact cleaning unit approximately 30cm x 20cm x 10cm for portability and compatibility with diverse window sizes.

Cleaning Mechanism: Rotating brushes, microfiber pads, or oscillating wipers with integrated ultrasonic spray for streak-free cleaning.

Sensors: AI-driven sensors to detect dirt levels, measure window dimensions, and assess weather conditions for adaptive operation.

Power Source: Solar panels and rechargeable batteries for autonomous and sustainable energy usage.

Safety Features: Includes tethering systems for high-rise applications and automatic shutdown mechanisms during malfunctions.

Materials:

Lightweight yet durable materials, such as ABS/PC plastic for casing.

Hydrophobic-coated glass for improved dirt resistance.

Silicone wipers for scratch-free cleaning.

Control System: Operable via a smartphone app and capable of integrating with centralized building management systems.

6.3 Manufacturing Technologies: Suggest Potential Processes

To ensure cost-efficiency and quality, the following manufacturing processes are recommended:

Injection Molding: For lightweight and durable plastic components, ensuring consistent quality in mass production.

3D Printing: Ideal for prototyping and creating intricate, customized parts for sensors and attachment mechanisms.

Ultrasonic Welding: Ensures secure, waterproof seals for plastic components.

Robotic Assembly: Enhances precision in assembling motors, sensors, and cleaning systems while minimizing errors.

Surface Coating Technologies: Applies hydrophobic coatings to maintain the system's self-cleaning properties.

Solar Panel Integration: Uses specialized processes to integrate solar panels seamlessly without compromising the device's compact design.

6.4 Packaging & Branding: Propose Branding and Packaging Ideas

Brand Name: SmartClear—a blend of innovation and clarity.

Tagline: "Clean Windows. No Hands. No Hassle." Emphasizing automation and ease.

Logo Design: Sleek and modern, featuring a stylized window and abstract design symbolizing transparency and innovation.

Brand Colors: Eco-friendly greens and whites to represent sustainability, complemented by accents of matte black for a high-tech aesthetic.

Packaging Design:

Sustainability: Recyclable and eco-friendly packaging materials.

Design Aesthetic: Minimalistic and modern to reflect the product's innovative features. Clean-cut lines and intuitive layouts showcase key attributes.

Instructional Manual: Available digitally via QR code to reduce paper waste. Highlights easy installation, operation, and sustainability benefits.

Presentation: Compact and sturdy packaging with clear labels, suitable for both residential and commercial customers.

6.5 Conclusion: Summarize Findings and Introduce the Next Chapter

This chapter detailed the positioning, design specifications, and manufacturing strategies for SmartClear, emphasizing its role as a cutting-edge, eco-friendly solution. Through a focus on sustainability, user needs, and advanced technology, SmartClear positions itself as a leader in automated window cleaning systems.

The next chapter will delve into market strategies, including customer demand analysis, pricing models, and strategic partnerships to ensure the product's successful launch and market penetration.

6.6 PRODUCT POSITIONING MAP

The Product Positioning Map below compares SmartClear with its main competitors along two axes: Level of Automation and Sustainability. SmartClear is positioned in the top-right quadrant, representing both high sustainability and high automation.

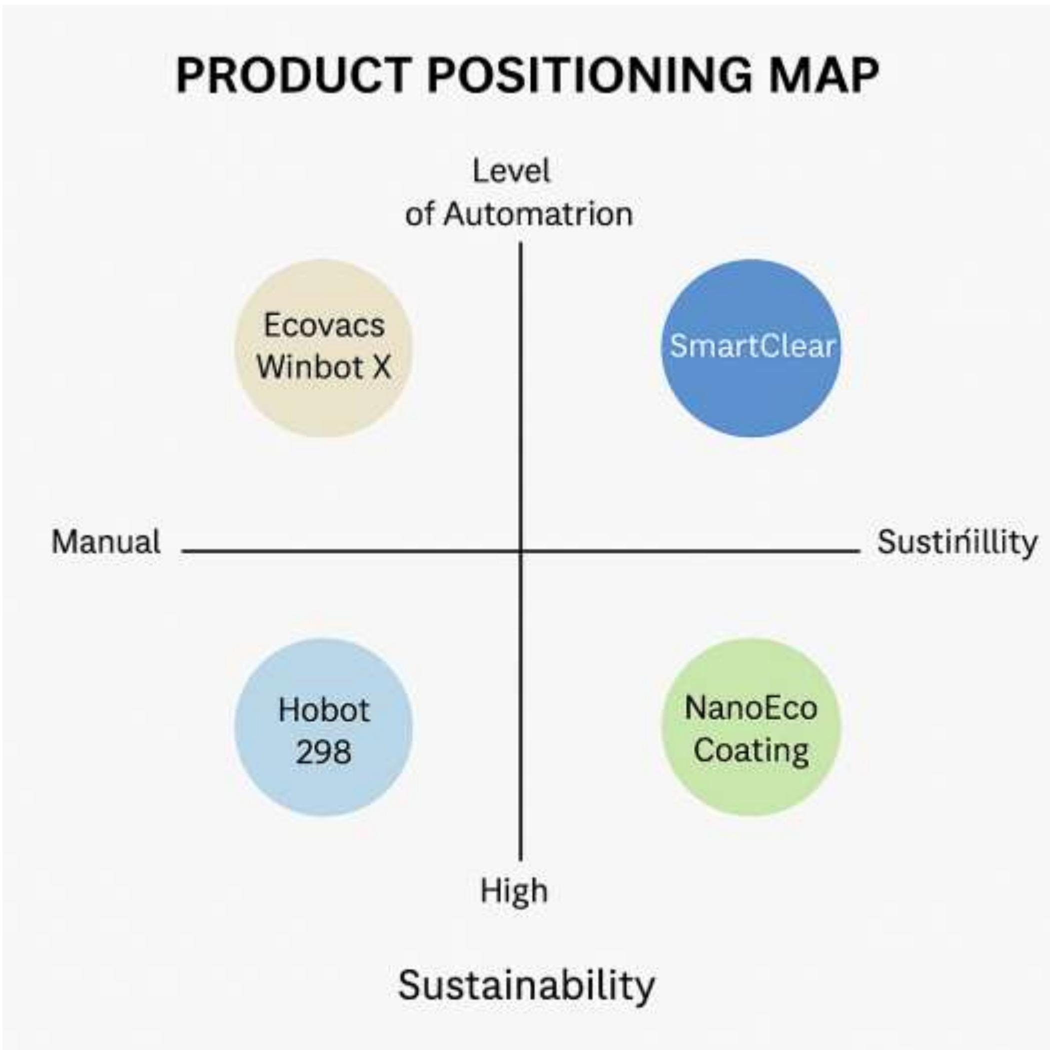

Figure 6.1
[Positioning Map]
[Ref: 43]

Chapter 7: Product Development Stage

7.1 Introduction

This chapter details the prototyping phase of SmartClear, transforming conceptual design into functional models. It captures the iterative process, technical development, and product validation steps required to bring the SmartClear system closer to real-world implementation. The prototype integrates user needs, technical innovation, and sustainability goals.

7.2 Problem Definition

Traditional window cleaning methods are labor-intensive, risky, especially for high-rise buildings, costly and environmentally harmful due to excessive water and chemical use. SmartClear addresses these challenges with an autonomous, water-conserving, solar-powered cleaning system that ensures safety and eco-friendliness.

7.3 Inspiration – Mood Board The mood board includes:

• **Shapes:** Streamlined, curved edges inspired by biomimicry (eyelids)

Figure 7.1 [Shape mood board showcasing biomimicry-inspired forms such as eyelid movement.] [compiled by the author from Ref : 44]

• **Textures:** Smooth, modular surfaces with minimal visual interruption.

Figure 7.2 [Texture references highlighting smooth, hydrophobic surfaces.] [compiled by the author from Ref :45]

• **Colors:** Neutral tones, matte black, and metallic finishes for a high-tech feel.

Figure 7.3 [Color palette emphasizing sleek, high-tech tones like matte black and silver] [compiled by the author from Ref: 46]

• **Environmental Cues:** Dusty high-rise urban settings like NEOM's The Line.

Figure 7.4 [Environmental mood board portraying dusty urban settings and smart city architectur] [compiled by the author from Ref :47]

Aesthetics

Figure 7.5 [Aesthetic mood board showcasing minimalist, functional, and modern design style, suited for contemporary urban buildings.] [compiled by the author from Ref :48]

Functions

Figure 7.6 [Functional inspiration board illustrating modular and compact mechanisms.] [compiled by the author from Ref :49]

Features

Figure 7.7 [Feature highlights including solar energy, fog removal, and wiper dynamics.] [compiled by the author from Ref :50]

7.4 Concept Generation

Initial ideation produced multiple sketches that explored different approaches to achieving the SmartClear concept. These included wiper systems that mimic the natural movement of eyelids, solar energy collection panels to provide sustainable power, compact modules designed to attach seamlessly to window frames, and heating wire systems inspired by car defoggers to prevent fog buildup.

7.5 Ideation Sketches

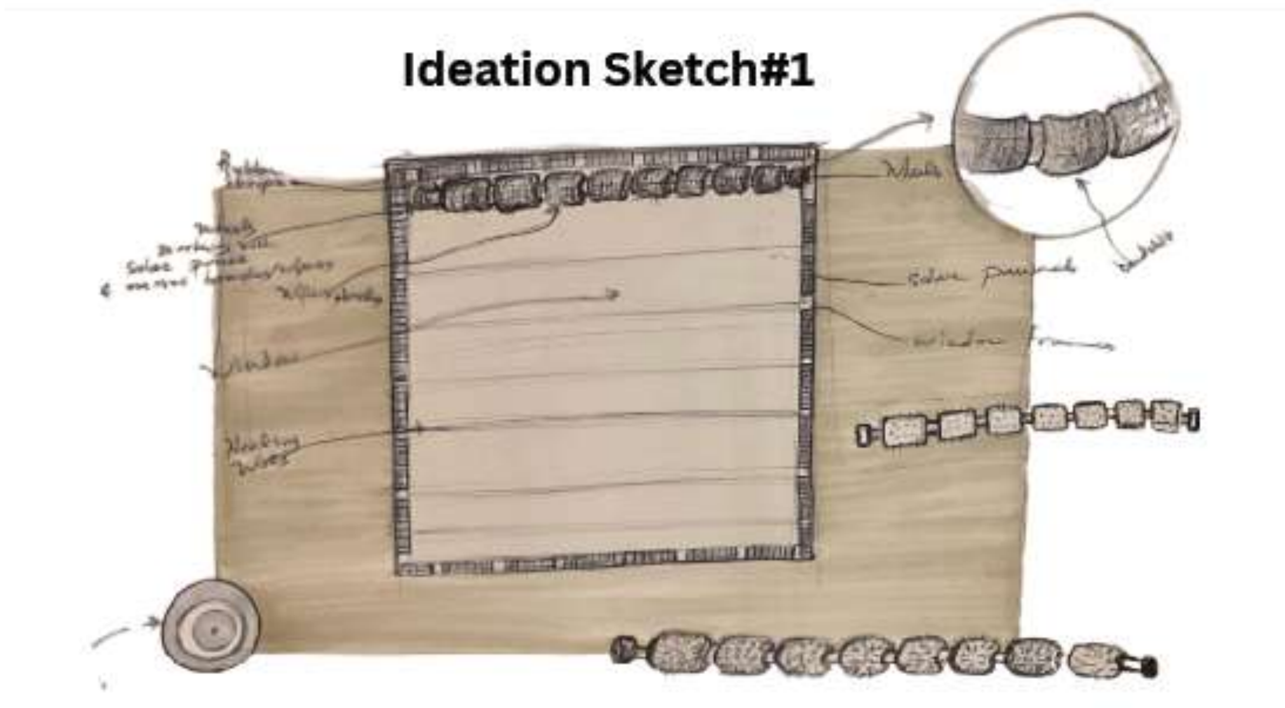

Figure 7.8 [Early concept sketch exploring initial SmartClear frame and wiper layout.] [Ref:51]

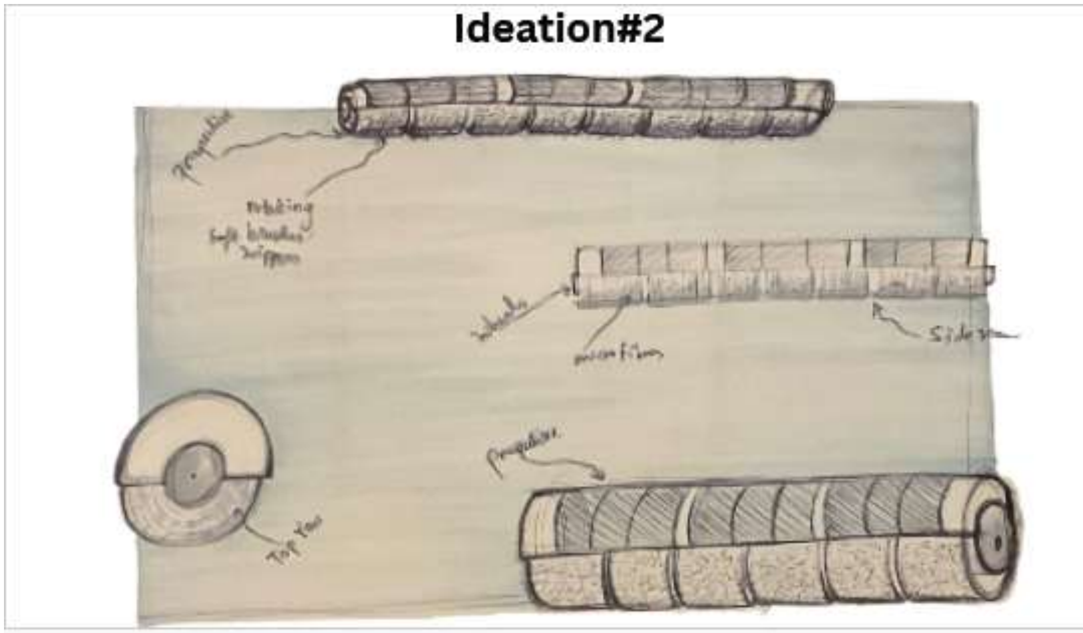

Figure 7.9 [Alternative design showing solar panel integration and control module.] [Ref:51]

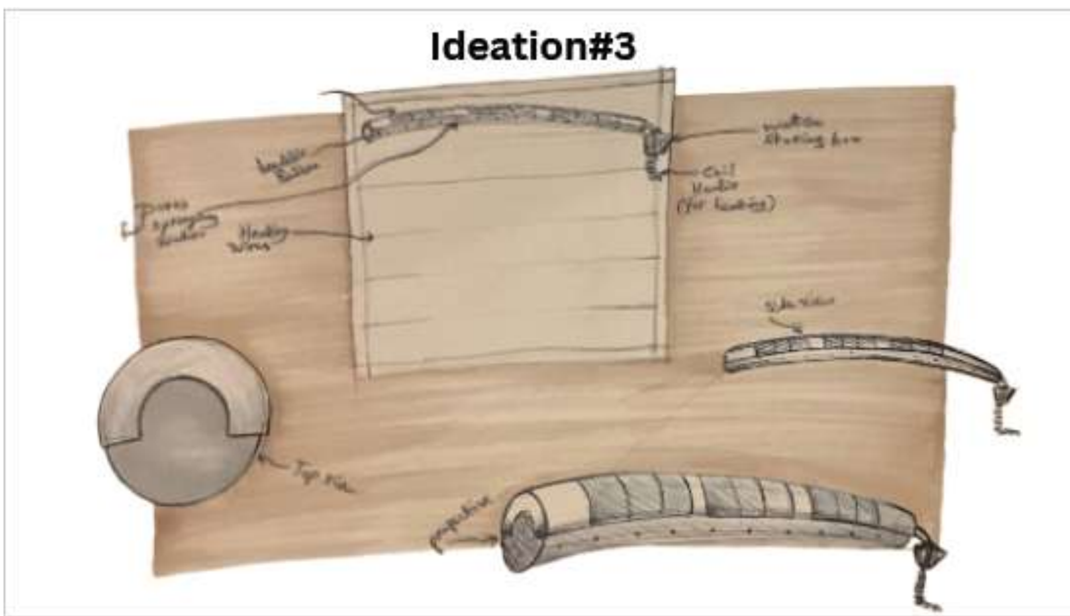

Figure 7.10 [Sketch of multi-angle wiper movement for larger windows.] [Ref:51]

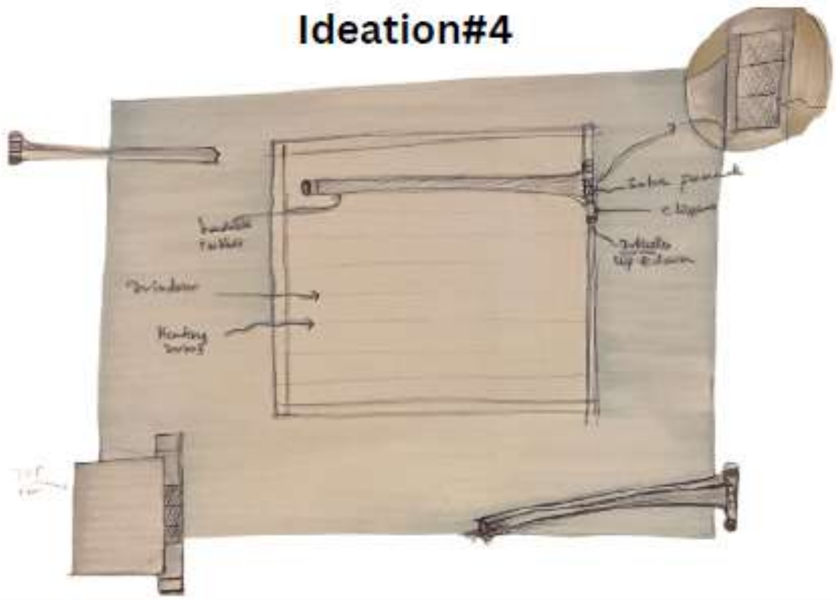

Figure 7.11 [Concept emphasizing detachable modular cleaning units.] [Ref:51]

7.6 Development Sketches:

The development sketches illustrate the evolution and refinement of the design concept, starting with a detailed sketch showing the mounting rail and screw interface to ensure secure and efficient installation. Subsequent sketches explore the integration of a solar panel with embedded heating wires, highlighting the functional innovation aimed at enhancing energy efficiency. The concept is further developed through compact form factor studies, tailored specifically for residential applications where space and aesthetics are crucial. Additionally, the sketches showcase an adaptive frame design, enabling flexible fitting across various window profiles to accommodate diverse architectural styles and installation needs.

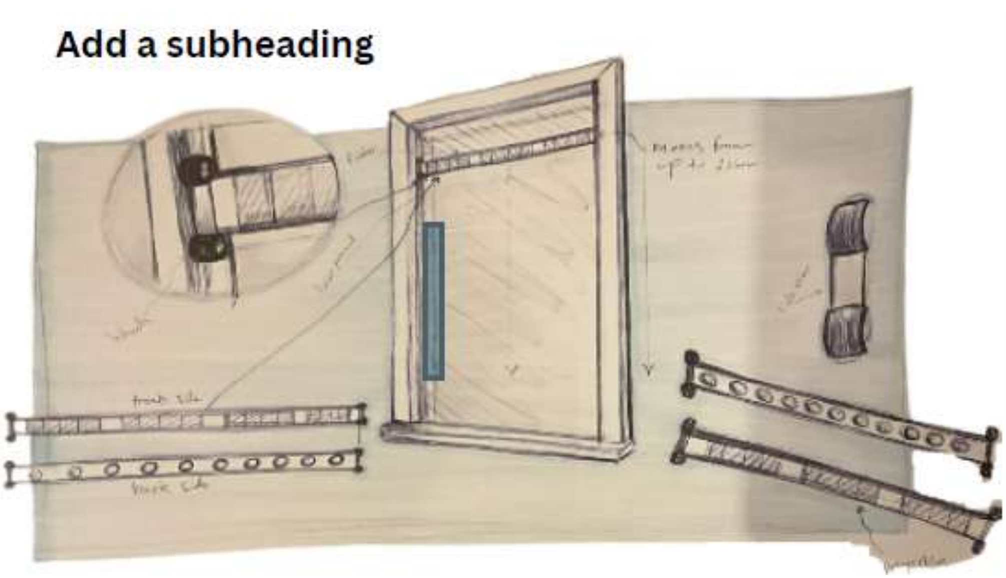

Figure 7.12 [Refined sketch showing mounting rail and screw interface.] [Ref:51]

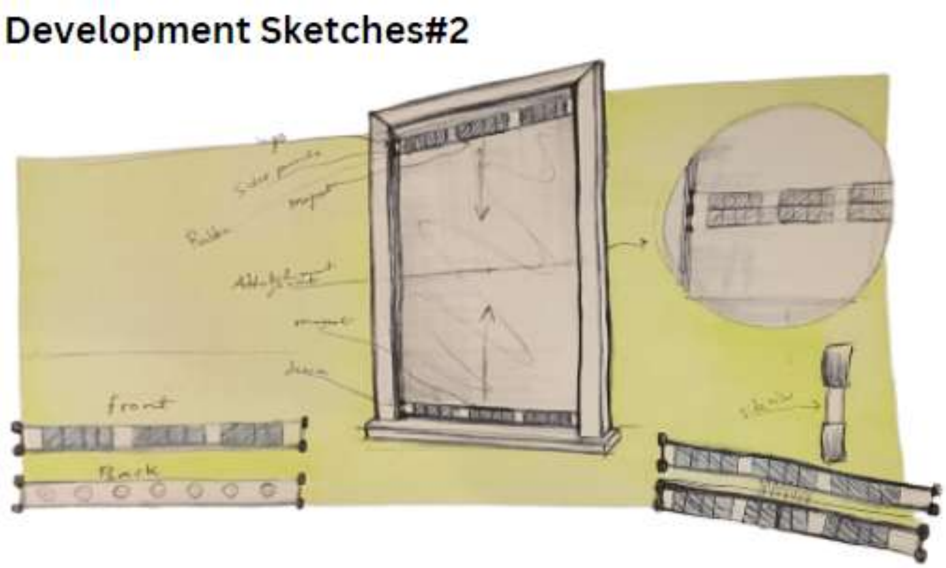

Figure 7.13 [Evolution of concept integrating solar panel with heating wires.] [Ref:51]

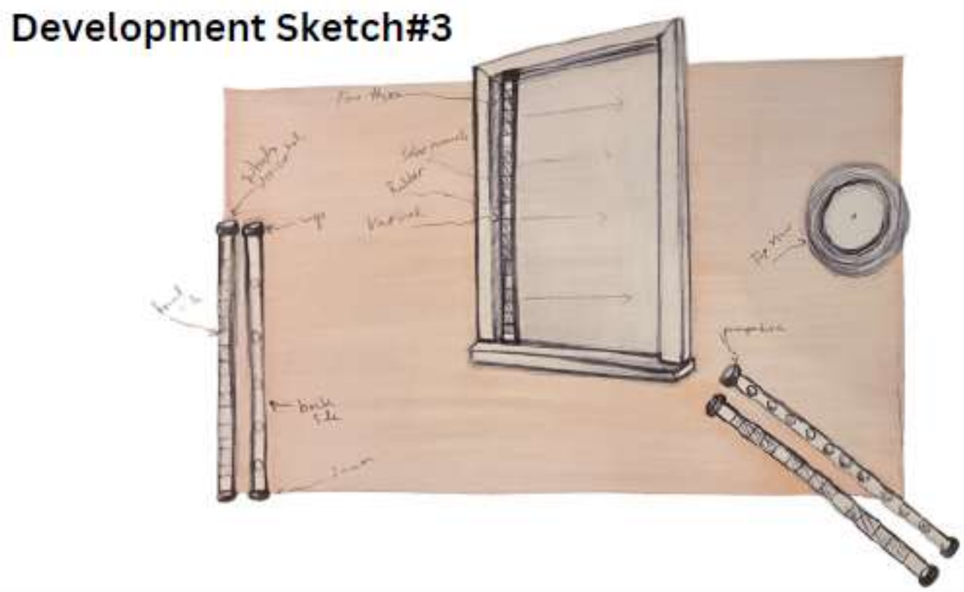

Figure 7.14 [Exploration of compact form factor for residential applications.] [Ref:51]

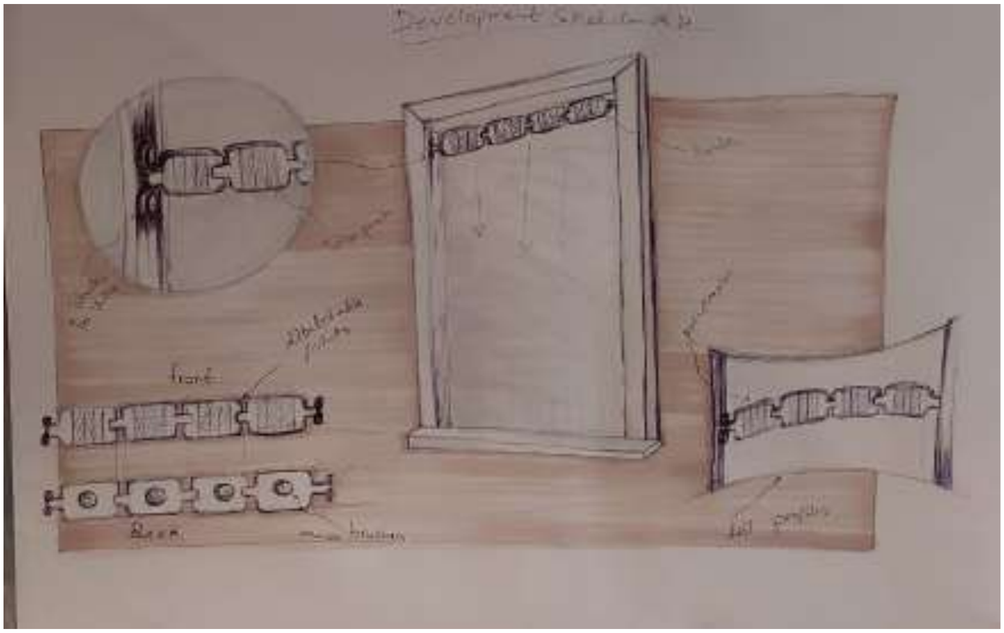

Figure 7.15 [Adaptive frame design allowing flexible fitting across window profiles.] [Ref:51]

7.7 Low-Fidelity Model

The low-fidelity model phase focuses on creating quick, cost-effective physical prototypes to validate core design decisions. These models help understand spatial layout, basic mechanics, and usability at an early stage.

7.8 Initial Model:

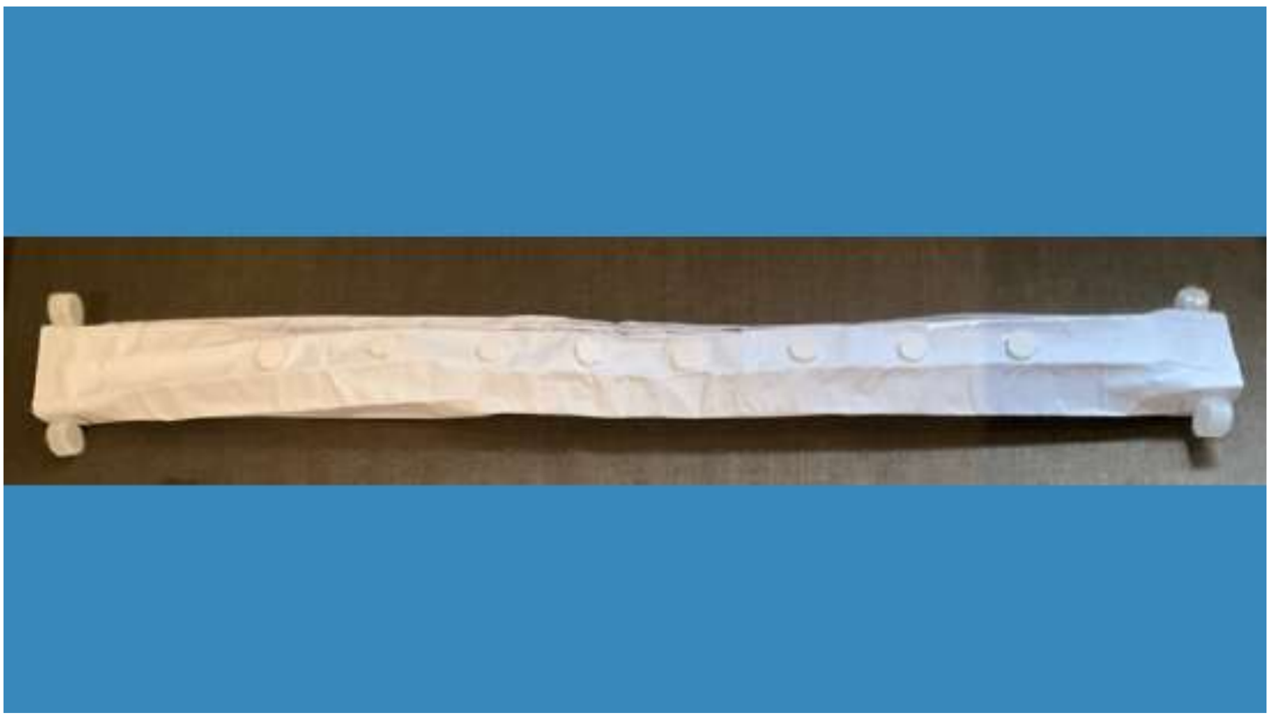

Figure 7.16 [SmartClear Initial Model] [Ref:51]

7.9 Mock ups:

Figure 7.17 [SmartClear Mock up Model 1] [Ref:51]

Figure 7.18 [SmartClear Mock up Model 2] [Ref:51]

Figure 7.19 [SmartClear Mock up Model 3] [Ref:51]

Figure 7.20 [SmartClear Mock up Model 4] [Ref:51]

Figure 7.21 [SmartClear Mock up Model 5] [Ref:51]

7.10 Ideation Sketch #1–#4

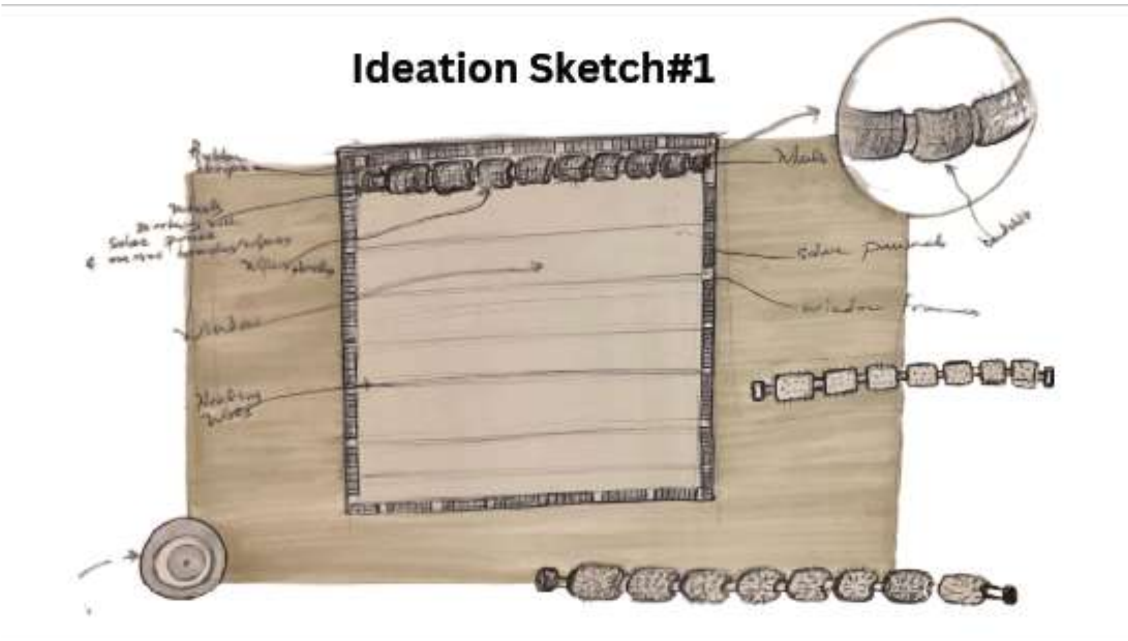

Figure 7.22 [Early concept sketch exploring initial SmartClear frame and wiper layout.] [Ref:51]

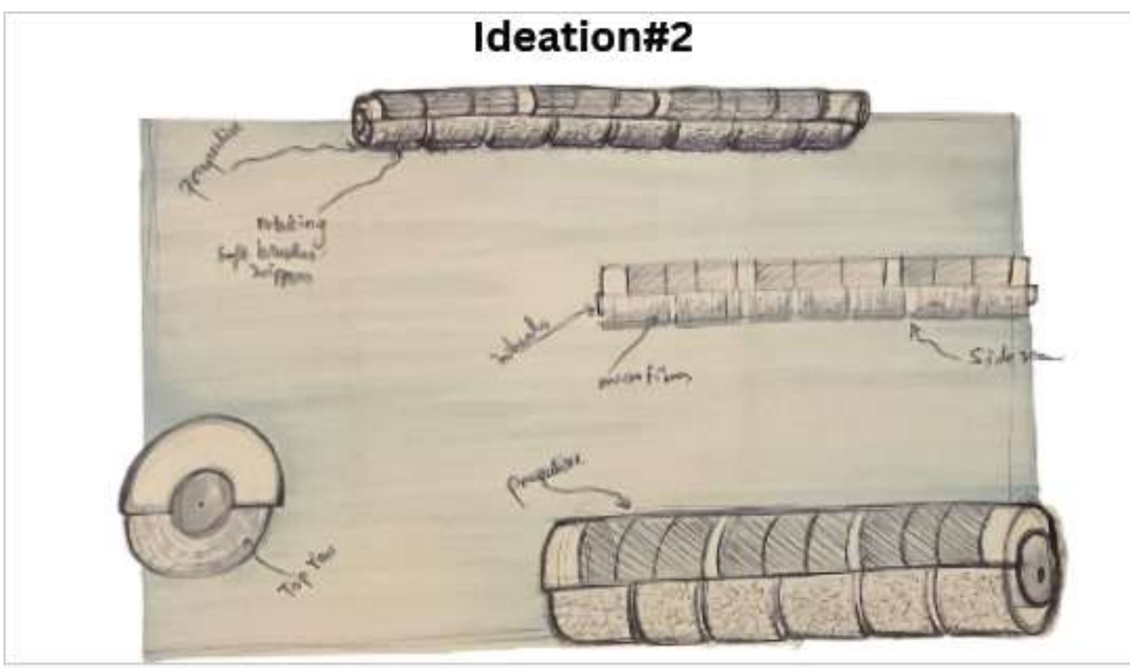

Figure 7.23 [Alternative design showing solar panel integration and control module.] [Ref:51]

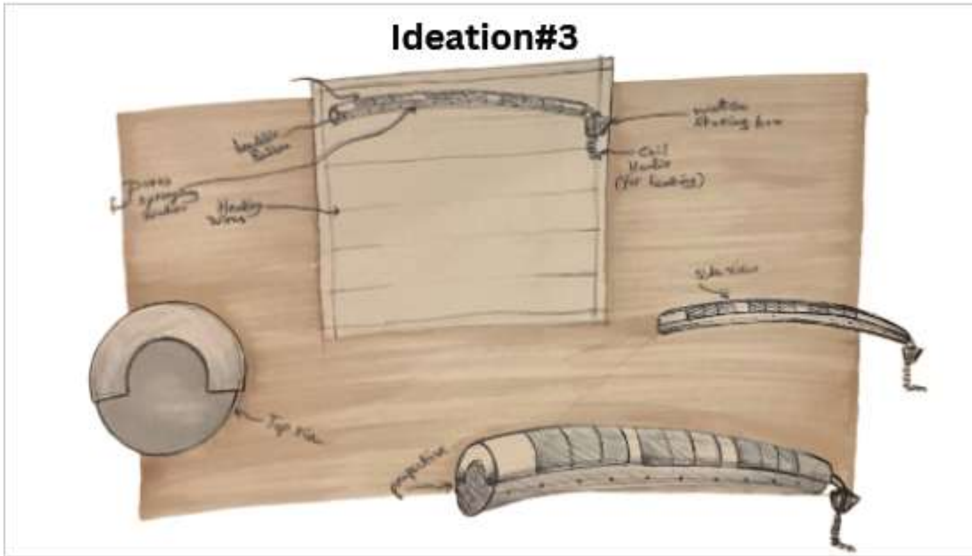

Figure 7.24 [Sketch of multi-angle wiper movement for larger windows.] [Ref:51]

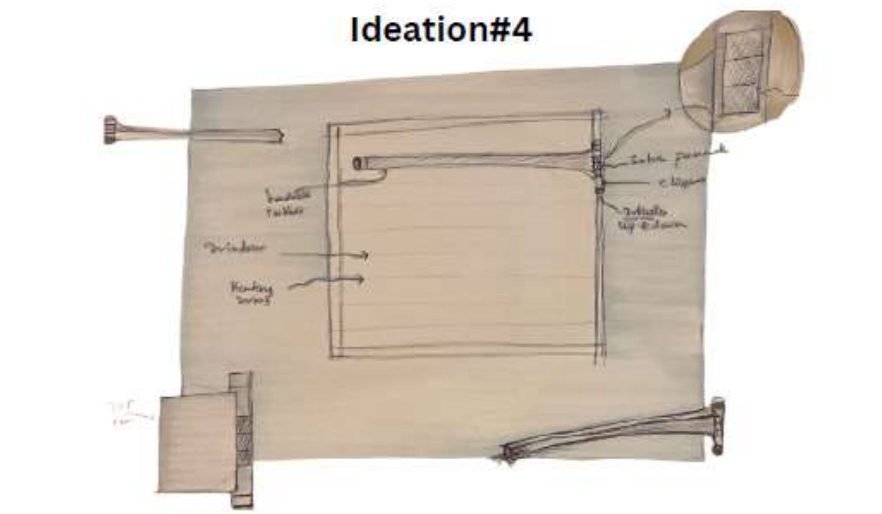

Figure 7.25 [Concept emphasizing detachable modular cleaning units.] [Ref:51]

Basic physical mockups and hand sketches (e.g., Ideation Sketch #1–#4) demonstrated:

- System shape and mounting mechanism.
- Movement direction of the wiper.
- General dimensions and volume distribution.

7.11 Pugh Matrix

This section presents a Pugh Matrix analysis used to evaluate multiple existing competitors against SmartClear using standardized criteria. The matrix supports the design selection process, highlighting strengths and weaknesses based on functionality, sustainability, cost, and usability.

The Pugh Matrix evaluates SmartClear against key competitors like the Hobot 298, Ecovacs Winbot X, and Nanoeco coating based on several criteria, including eco-friendliness, automation, integration, and user-friendliness. Using the Hobot 298 as the base product for comparison, SmartClear scored the highest in eco-friendliness, integration with smart infrastructure, and maintenance reduction. These factors highlight SmartClear's superior environmental impact, seamless compatibility with modern smart systems, and reduced upkeep needs, positioning it as a more sustainable and user-friendly choice compared to its competitors in the market.

Criteria	SmartClear	Hobot 298	Ecovacs Winbot X	NanoEco Coating	Evaluation
Eco-Friendliness	+	0	-	+	SmartClear leads in sustainability
Automation	+	+	+	-	SmartClear is highly automated
Smart Integration	+	0	0	-	Only SmartClear supports smart cities
User-Friendly Design	+	0	+	+	SmartClear is compact and easy to use

Table 3 Pugh Matrix

7.12 Analysis for Final Design

The design evaluation of SmartClear focused on functionality in dusty and humid environments, user safety during installation and operation, and compatibility with various window sizes. It emphasizes sustainability with no chemicals, minimal water use, and solar power. The product is designed to integrate seamlessly with modern architecture and operates fully autonomously, ensuring ease of use and reliability in diverse conditions.

Detail Design (Sketches + CAD) : Final design includes:

Front, side, top, and back views.

Functional components like the wiper blade, solar panel, rail mount, and heating wires.

Minimalist, movement inspired from eyelids and modular frame inspired by Dyson Airblade and Tesla Powerwall.

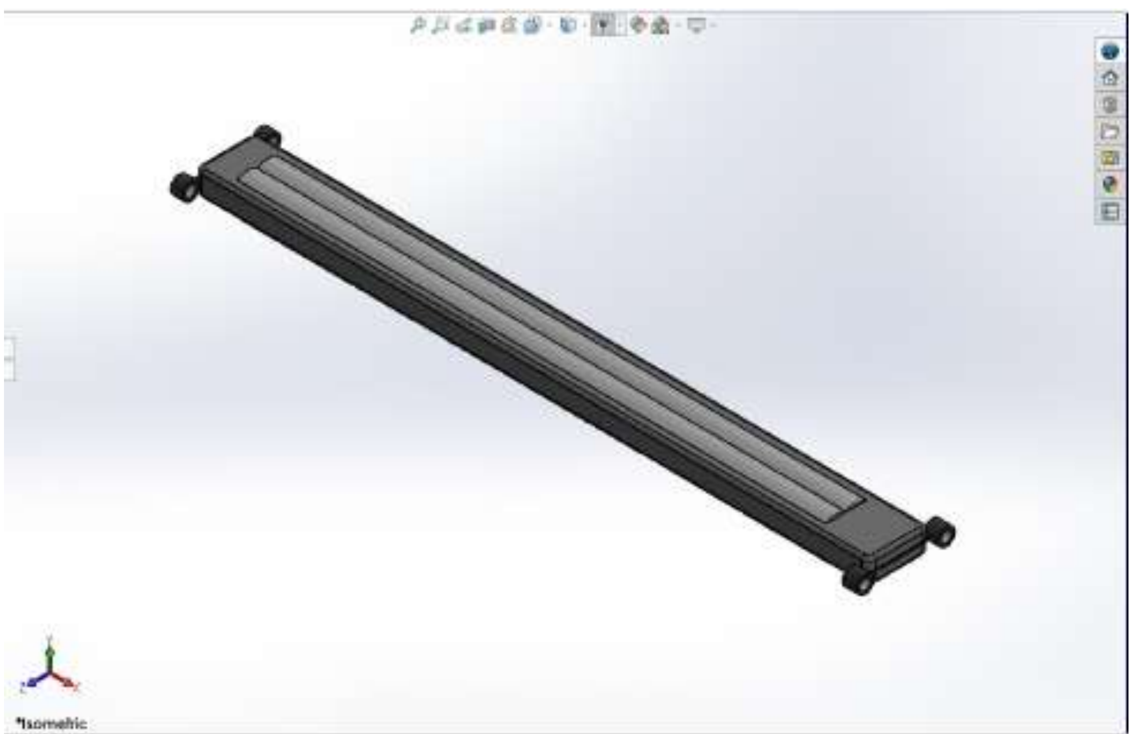

Figure 7.26 [perspective view of development model] [Ref:51]

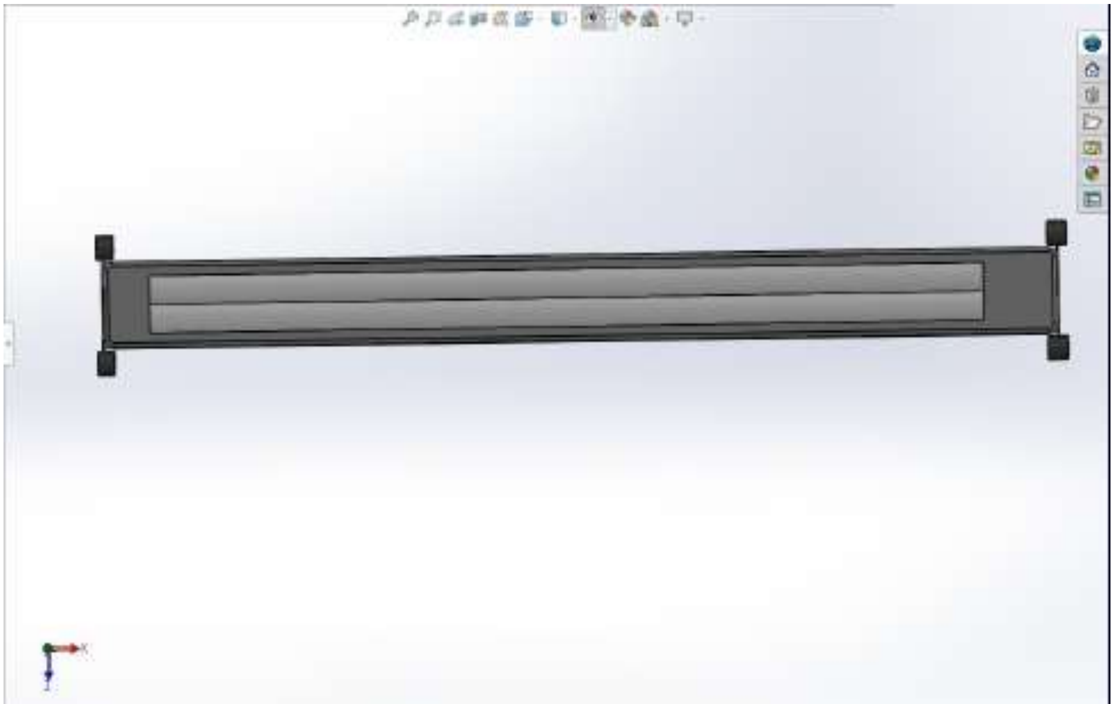

Figure 7.27 [Back view showing control housing and rail support. Development model] [Ref:51]

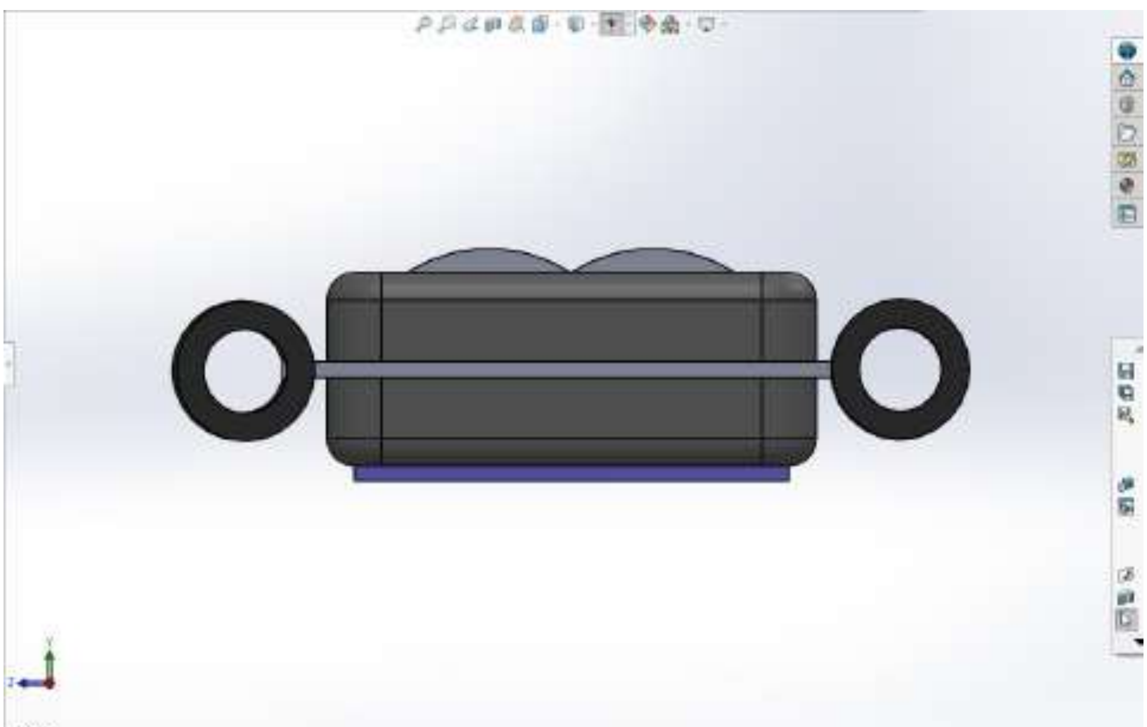

Figure 7.28 [Top view highlighting solar panel alignment. Development model] [Ref:51]

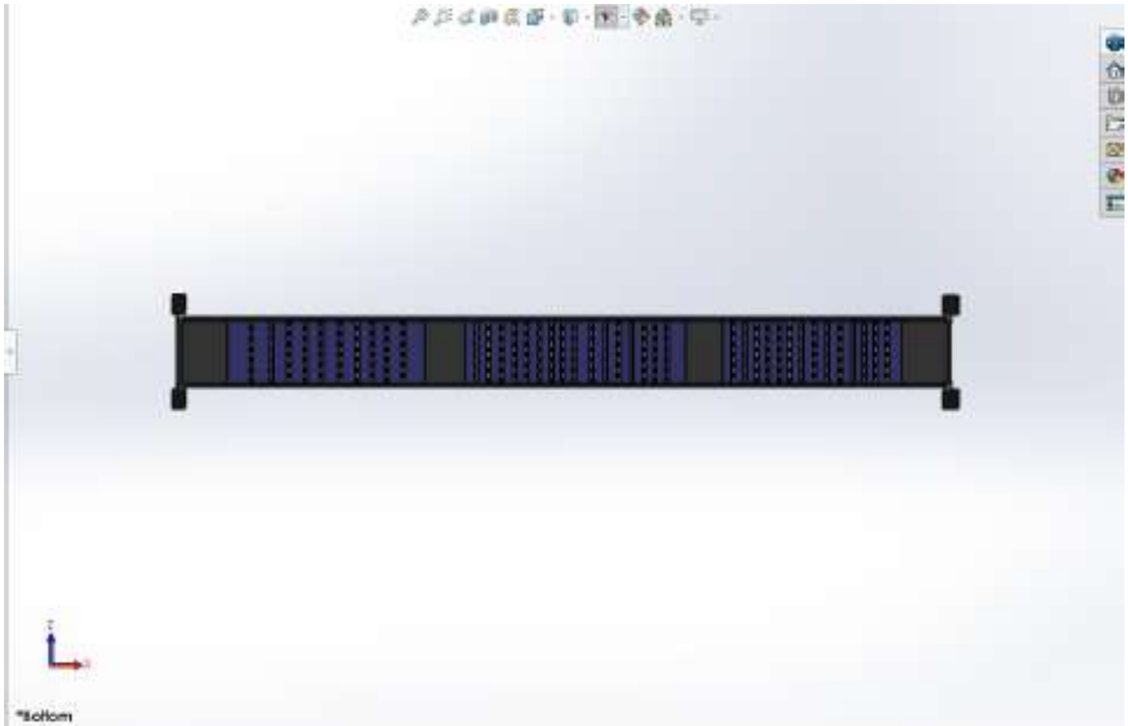

Figure 7.29 [Front view of SmartClear CAD model with visible wiper strip. Development model]

[Ref:51]

Figure 7.30 [Side view. Development model] [Ref:51]

Figure 7.31 [Front view of SmartClear CAD model with visible wiper strip. Development model]

[Ref:51]

Figure 7.32 [Front view of SmartClear CAD model with visible wiper strip.] [Ref:51]

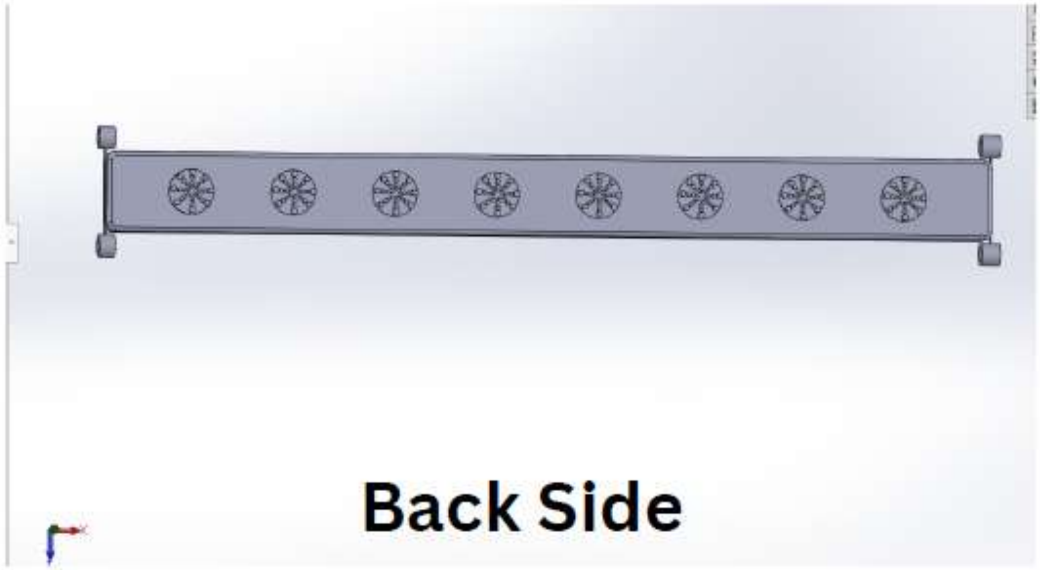

Figure 7.33 [Back view showing control housing and rail support.] [Ref:51]

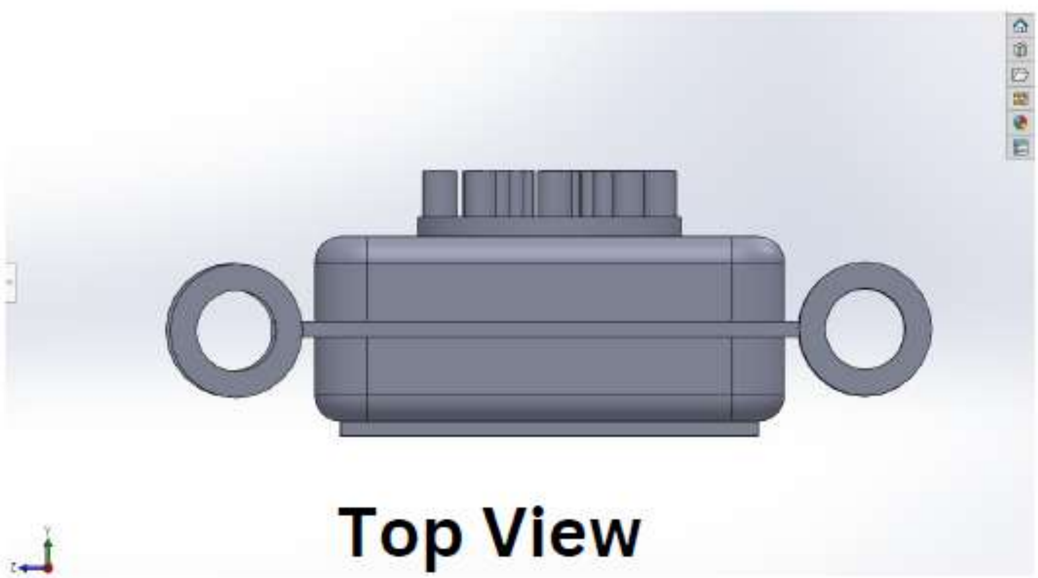

Figure 7.34 [Top view highlighting solar panel alignment.] [Ref:51]

Figure 7.35 [Side view illustrating low-profile design and wall attachment points.] [Ref:51]

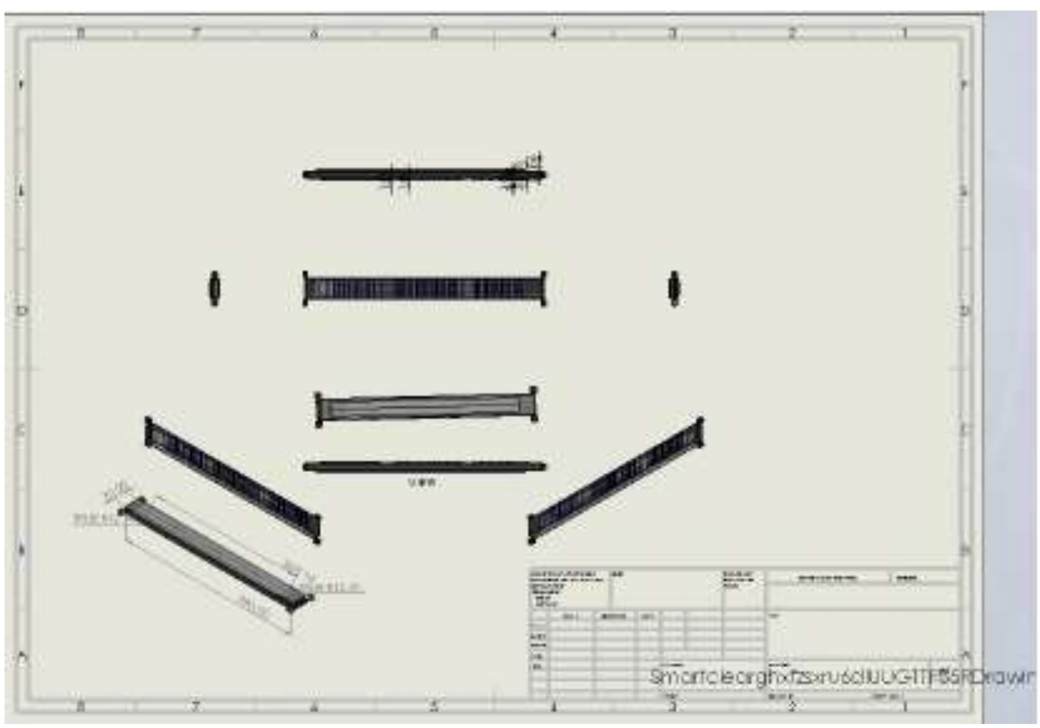

Figure 7.36 [2D View. Development model] [Ref:51]

Development Renders

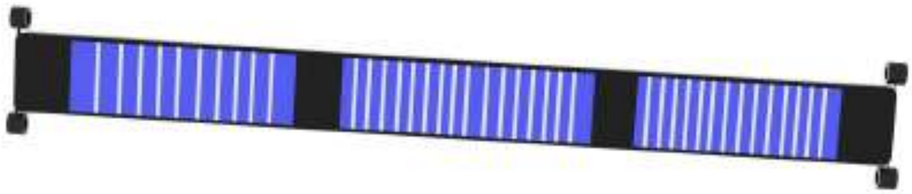

Figure 7.37 [Front View Render] [Ref:51]

Figure 7.38 [Back View Render] [Ref:51]

Figure 7.39 [Perspective View] [Ref:51]

Figure 7.40 [Back View] [Ref:51]

Figure 7.41 [Back View] [Ref:51]

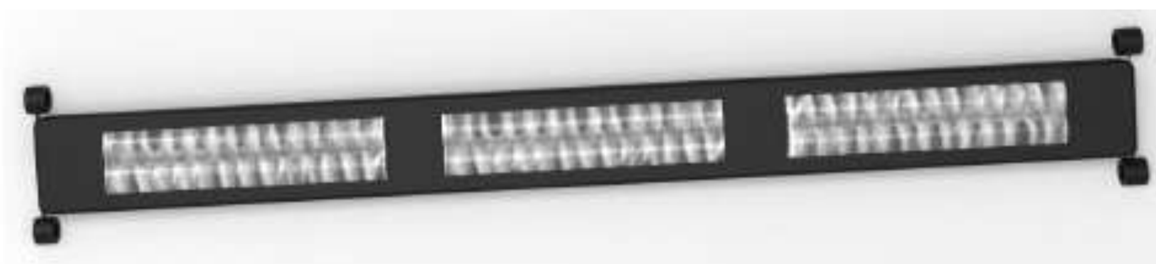

Figure 7.42 [Back View] [Ref:51]

Figure 7.43 [Perspective View] [Ref:51]

Figure 7.44 [Stages of Development Models Renders] [Ref:51]

Figure 7.45 [Front View] [Ref:51]

Figure 7.46 [Front View] [Ref:51

Figure 7.47 [Bottom View] [Ref:51

Final Design Renders:

Figure 7.48 [Perspective View] [Ref:51]

Figure 7.49 [Final Render Smart Clear on Rail] [Ref:51]

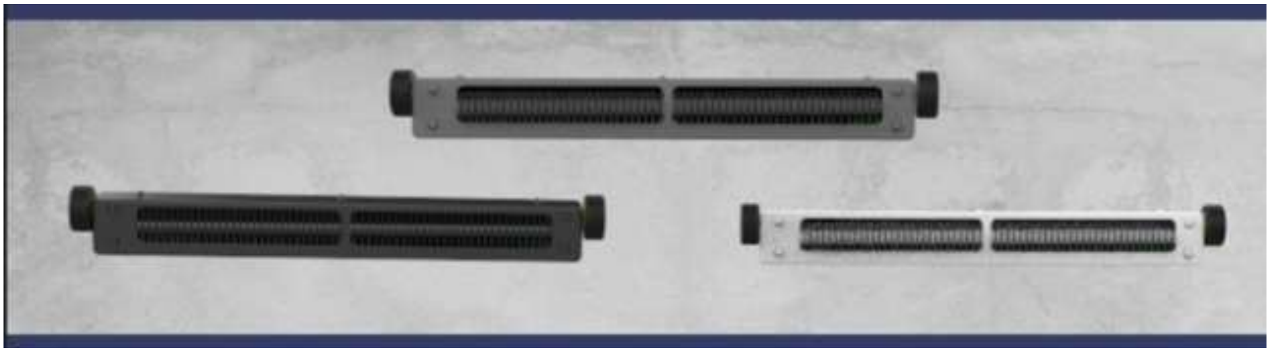

Figure 7.50 [Color Options] [Ref:51]

Figure 7.51 [Perspective Views] [Ref:51]

Figure 7.52 [Sizes On Demand View] [Ref:51]

Figure 7.53 [Color Options] [Ref:51]

Figure 7.54 [Smart Clear on Rail] [Ref:51]

Figure 7.55 [Smart Clear on Rail (Perspective View)] [Ref:51]

Figure 7.56 [Perspective View] [Ref:51]

Figure 7.57 [Back View of Smart Clear on Rail] [Ref:51]

Figure 7.58 [Smart Clear on Rail (Perspective View)] [Ref:51]

Figure 7.59 [Back View of Smart Clear on Rail] [Ref:51]

Figure 7.60 [Back View of Smart Clear on Rail] [Ref:51]

Detail Component Drawing – With Dimensions

Key dimensions:

Height: 100 cm

Width: 7 cm

Depth: 5–7 cm (tapered)

Wiper track length: 90 cm

Mounting brackets: 46 cm (variable based on window size)

All measurements adhere to ergonomic and installation constraints for residential and commercial high-rise buildings.

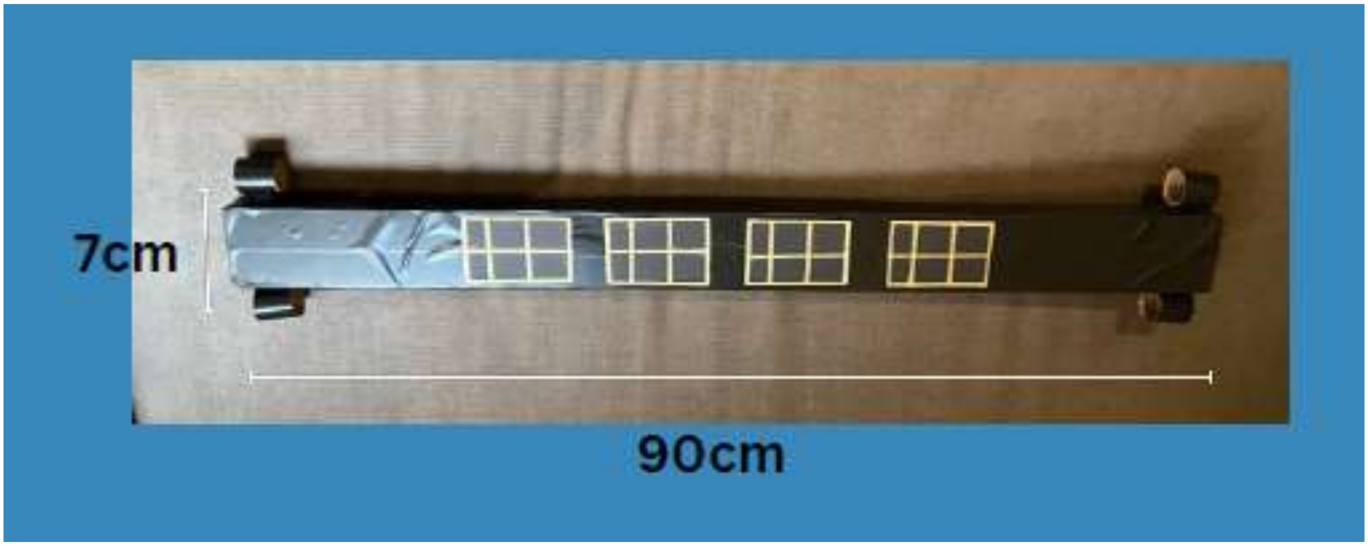

Figure 7.61 [SmartClear overall dimensions—height 100 cm, width 7 cm, depth 5–7 cm.] [Ref:51]

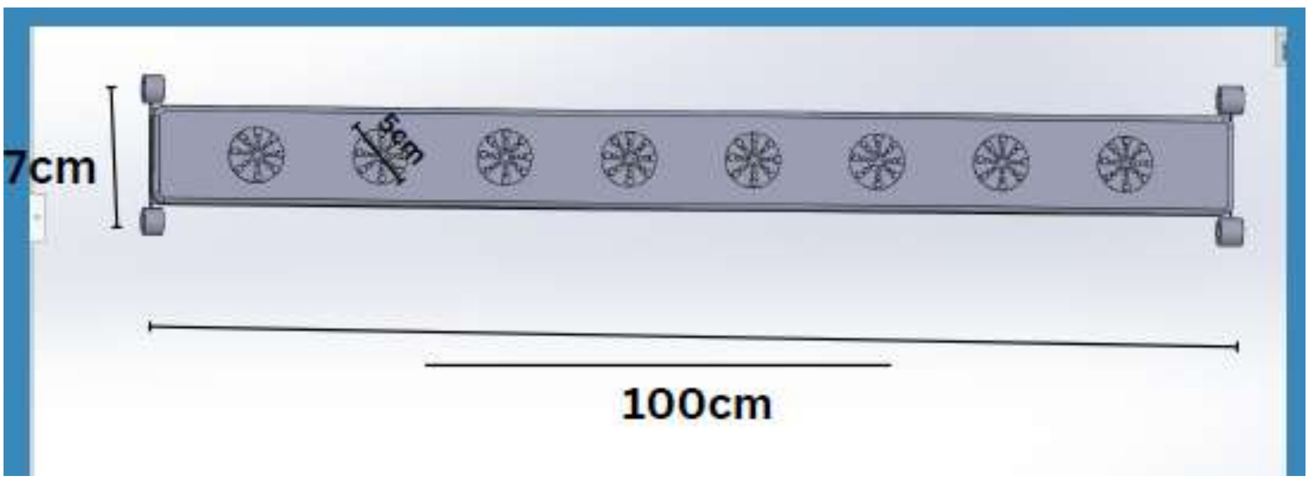

Figure 7.62 [Wiper track length and modular rail layout.] [Ref:51]

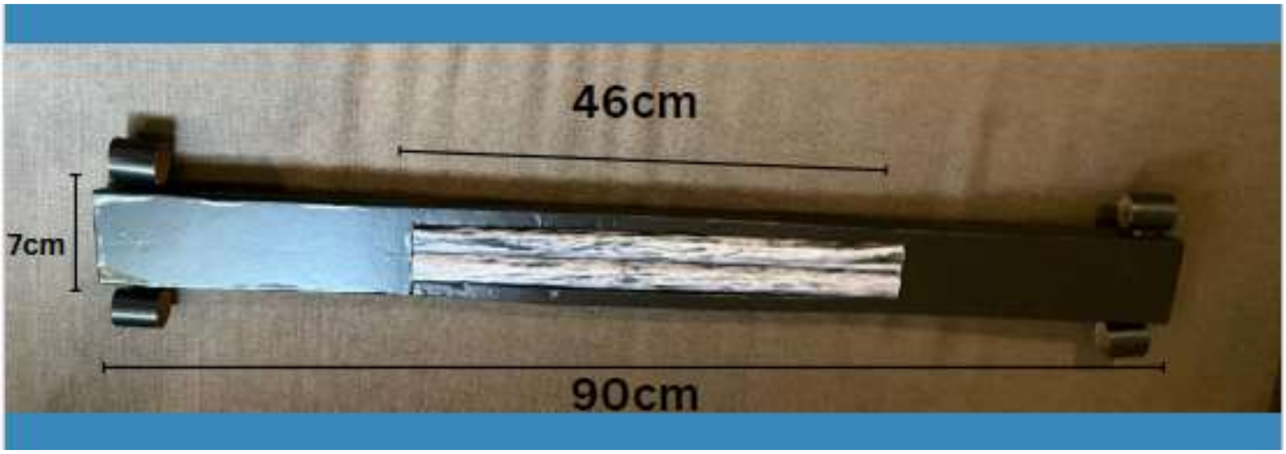

Figure 7.63 [Mounting structure and screw position diagram.] [Ref:51]

Technical Design – Electromechanical Parts

Power Source: Solar panels integrated into the frame.

Heating System: Embedded wires melt fog (rear-defogger mechanism).

Wiping Mechanism: Oscillating or rolling microfiber or rubber blade.

Control Unit: Microcontroller for AI-driven dirt detection and path optimization.

Sensors: Humidity, dirt, light exposure, and temperature sensors for adaptive cleaning.

Development Model:

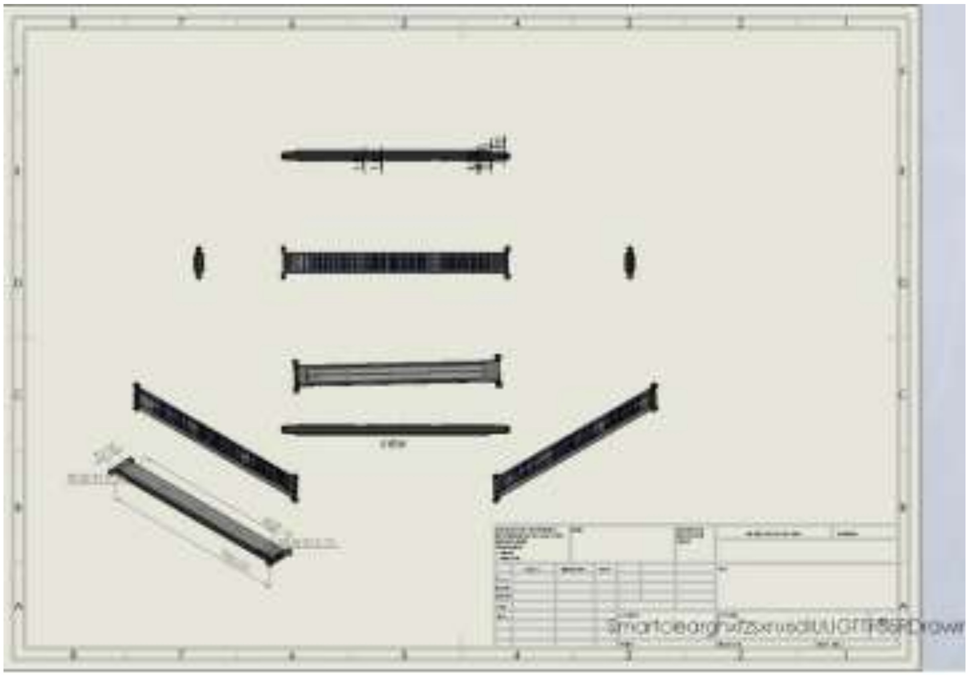

Figure 7.64 [2D view] [Ref:51]

Final Model:

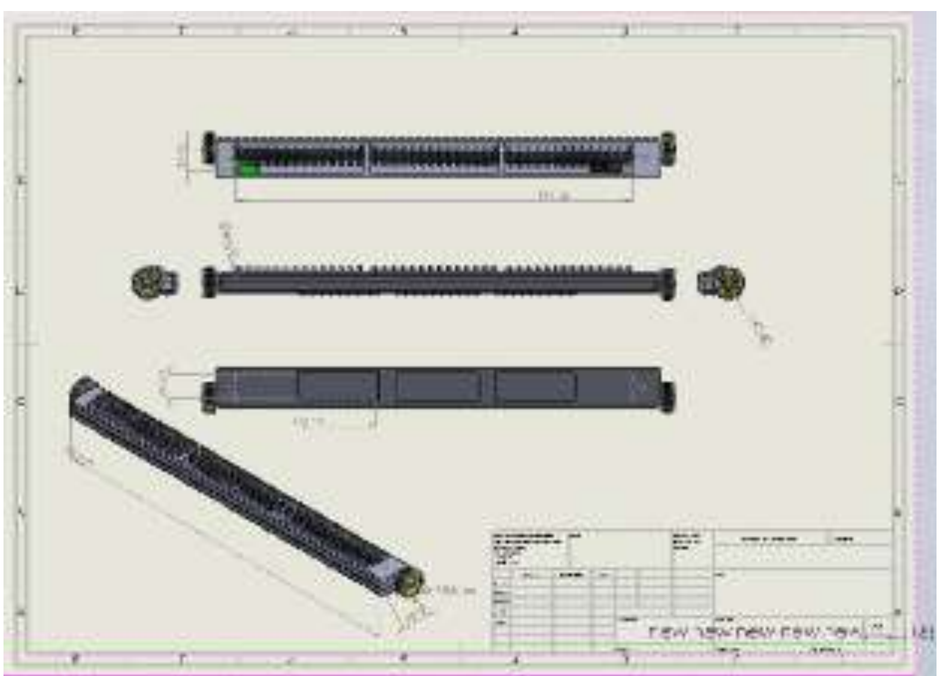

Figure 7.65 [2D view] [Ref:51]

7.13 Prototyping Stage – Soft and Hard

Soft Prototypes: CAD models, mockups using foam and 3D prints to simulate shape and interaction.

Hard Prototypes: Working system with integrated components tested on window mockups for mechanical movement, solar charging, and water condensation cleaning.

7.14 3D Printing

Used to prototype:

Wiper housing and blade structure.

Sensor mountings.

Modular frame ends and adjustable attachments.

Materials: PLA and ABS for strength and heat resistance.

Figure 7.66 [Front View of the Final Prototype] [Ref:51]

Figure 7.67 [Back View of the Final Prototype] [Ref:51]

Figure 7.68 [Final Model Prototype] [Ref:51]

Figure 7.69 [Rail Prototype] [Ref:51]

Figure 7.70 [small/mini Prototype for Final model Style one old version style] [Ref:51]

Figure 7.71 [Mini Prototype Top View] [Ref:51]

7.15 Product Testing

Tests conducted:

Functional: Wiper sweep efficiency, fog clearing in humid chambers, solar charge retention.

User: Ease of installation, app interface trials, sound level analysis.

Durability: Exposure to dust, UV light, and simulated wind load.

Feedback from user scenarios (e.g., Sarah in a 3rd-floor flat) led to improvements in safety, accessibility, and cleaning reach.

7.16 Branding

Name: SmartClear

Logo: Futuristic, clean lines suggesting clarity and motion.

Tagline: "Clean Windows. No Hands. No Hassle."

Visual Identity: Black, green, and silver palette reflecting eco-tech aesthetics.

7.17 Packaging

Eco-friendly, recyclable material.

Compact box with protective foam inserts for solar panel and wiper.

Digital manual via QR code (reduces paper).

Modular compartments for easy unboxing and reuse.

Figure 7.72 [PACKAGING DESIGN MOCK-UP1] [Ref:20]

Figure 7.73 [PACKAGING DESIGN MOCK-UP2] [Ref: 20]

7.18 Different Product Options

Standard SmartClear – Residential use.

SmartClear Pro – High-rise commercial application with extended rail.

SmartClear Lite – Compact version for small windows.

SmartClear SmartHome+ – IoT integrated model with app and voice assistant control.

7.19 User Scenario

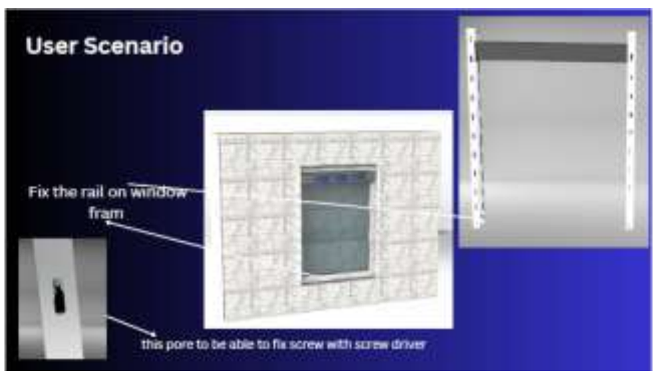

Figure 7.74 [User Scenario] [Ref:51]

 Installation:

Mount SmartClear by fixing the rail onto the window or window frame using screws through the provided pore using a screwdriver.

 Solar Power Activation:

Once mounted, the built-in solar panel charges automatically from sunlight. After the initial charge, it remains powered continuously by solar energy.

 Automatic Cleaning Trigger:

Smart sensors detect the presence of dust, dirt, or fog on the window surface.

 Self-Operating Mechanism:

The device begins cleaning automatically — moving from top to bottom or vice versa, wiping away grime and moisture without any manual effort.

 Eco-Friendly Cleaning:

Condensed water is collected and reused during cleaning for water efficiency & its powered from the energy source sun collecting it by solar pannel .

 Low Maintenance:

SmartClear requires no remote control and operates fully autonomously.

Every two years, it sends an alert via app to replace internal brushes. It includes an auto self-cleaning feature for ongoing hygiene.

Final Posters

Poster1

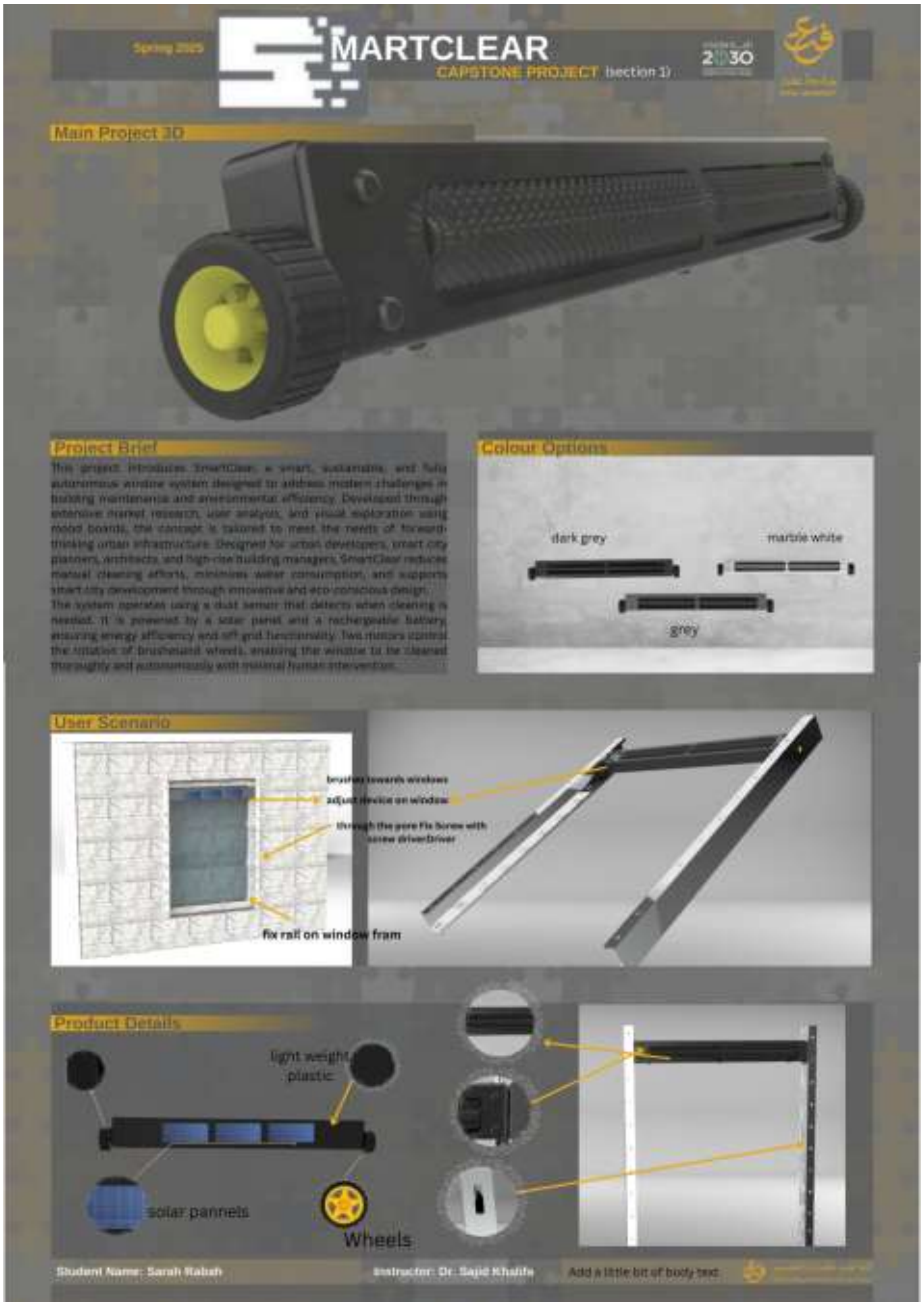

Figure 7.75 [Poster showing Smart Clear brief and User Scenario] [Ref:51]

Poster2

Figure 7.76 [Poster Showing Smart Clear Development and Final Sketches Details] [Ref:51]

Poster3

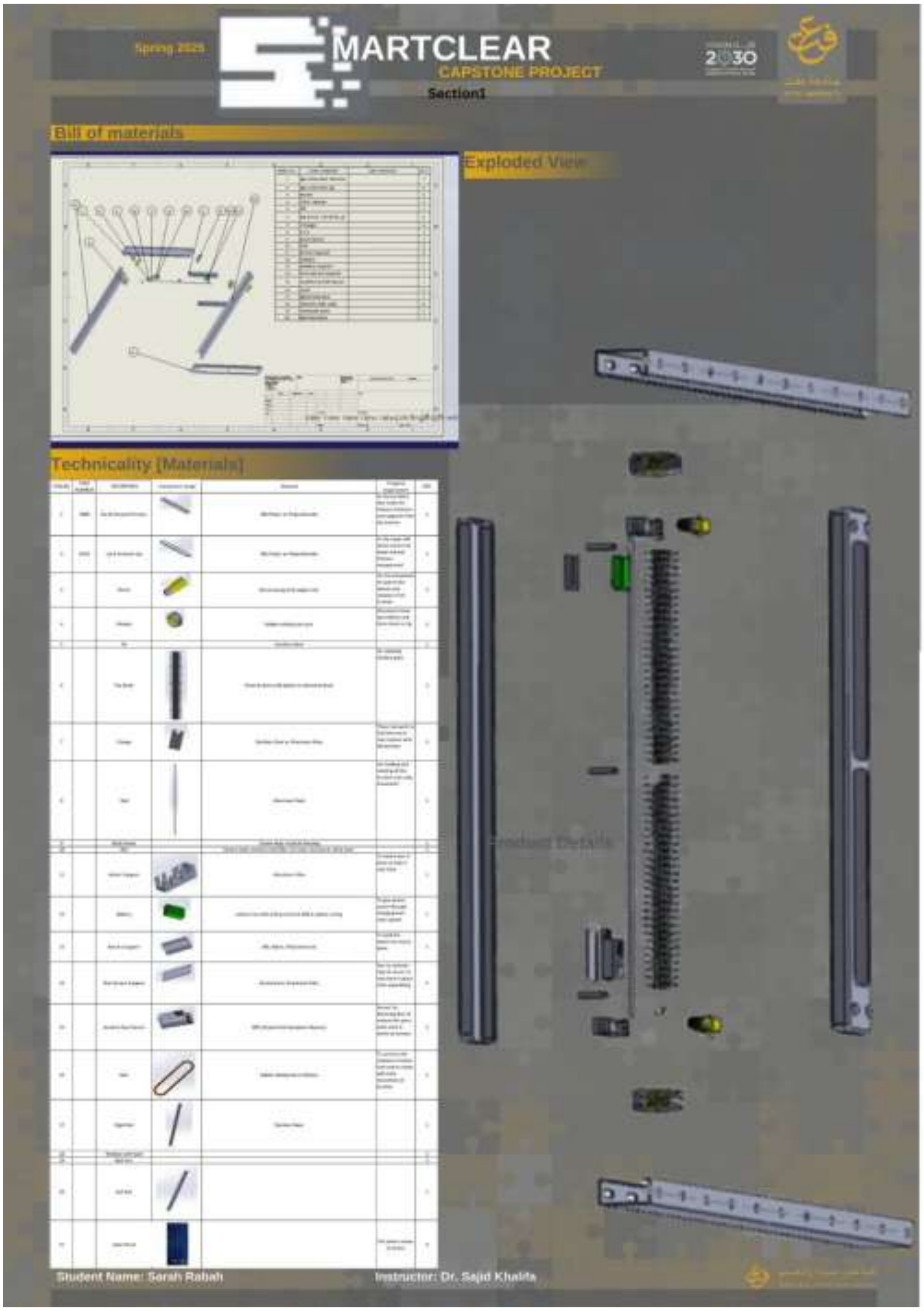

Figure 7.77 [Poster Showing Exploded View of Smart Clear with Components and its Materials] [Ref:51]

Chapter Conclusion

The prototyping phase of SmartClear marked a critical stage in transforming the idea from conceptual sketches into a functional and testable product. This stage validated the feasibility of merging biomimicry with sustainable smart technologies, while the iterative design process ensured steady progress through testing and refinement. Each cycle of improvement from initial sketches and digital simulations to assembling and testing physical models allowed the design to adapt to user needs, material performance, and environmental factors. These refinements helped achieve a balance between innovation and practicality, while ensuring that SmartClear's features aligned with its intended objectives of efficiency, safety, and user convenience.

By the conclusion of this phase, SmartClear had proven itself as more than just a theoretical concept. The functional prototype embodied sustainable features such as solar-powered operation, energy efficiency, and environmentally friendly materials, while its eyelid-inspired motion demonstrated how biomimicry can lead to effective design solutions. User-centered adjustments, such as sensor placement and improved usability, further emphasized the product's reliability and practicality. Overall, this stage laid the foundation for future development and larger-scale applications, particularly in high-rise urban environments where automated, safe, and sustainable window-cleaning solutions are urgently needed.

Discussion and Evaluation

The results of the prototyping phase demonstrated that SmartClear successfully achieved its main goals of performance, safety, and sustainability. The design proved effective in replicating natural cleaning mechanisms through its eyelid-inspired wiper system, while solar energy harvesting reinforced its environmentally friendly approach. Performance tests showed consistent cleaning efficiency, stable operation, and user-friendly automation. These outcomes confirm the value of combining biomimicry, sustainability, and smart technology into a single system, positioning SmartClear as an innovative product with strong potential in modern urban contexts.

At the same time, the evaluation revealed opportunities for improvement that will guide the next development stage. While the mounting system was stable under normal use, it requires reinforcement for extreme weather conditions such as high winds and dust storms. Similarly, the edge detection mechanism, although functional, could be enhanced to improve accuracy on curved or irregular window shapes. Addressing these refinements, alongside optimizing manufacturing processes, will be essential for scaling production and ensuring long-term reliability. Moving forward, pilot testing in smart urban environments such as NEOM's The Line will provide valuable insights into user adoption, integration with building systems, and real-world performance, ensuring SmartClear evolves into a practical, scalable solution for sustainable city living.

References:

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