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Design and Development of Smart Wardrobe Technology

Mikhail Filatov
Minnesota State University, Mankato

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By

Mikhail Filatov

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This thesis has been examined and approved by the following members of the student's committee.

Advisor

Name	Signature

Committee Member

Name	Signature

Committee Member

Name	Signature

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Abstract

The increasing demand for online shopping in the 21st century is causing rapid growth in technology and methods in marketing and sales fields. Present thesis work scrutinizes the process of design and development of the device that simplifies the process of trying on and buying clothes in online retail stores, the development of which is based on the known basics of operational, mechanical, and electrical designs for computational systems, with account for ergonomics and manufacturing sustainability. The following research represents the market analysis for competition identification, description of all operational modes of the system, list of mechanical and electrical components for stable operation, and sustainability rating of the device from manufacturing perspective.

Research Work Summary

Current work covers several areas of concept and prototype development, and is built on basis of existing technologies, hence the part of presented work falls out of scope of the research.

Scope of Work:

- **Evaluation of the market.**

  Targets the evaluation of the e-market trends, and identification of the competitor products.

- **Development of Visual Design**

  Targets the development of all operational screens: icons selection, design on the interaction areas, location of widgets, location of buttons, and projection styles.

- **Development of Operational Logic and Controls**

  Targets the development of control style, operational logic, of operational flow of the system.

- **Development of Electrical Design**

  Targets the development of electrical diagram (Single-Line) and selection of the components required for the reliable and optimal operation of the system.

- **Development of Mechanical Design**

  Targets the design of mechanical system from component packaging, sustainability, and esthetical standpoints. As well as selection of the components for the reliable and optimal operation of the system, and their implementation through Solidworks software.

Out of Scope:

- **Development of Body Tracking Software**

  The body tracking application used in the research is the open-source software – Lens Studio, developed by Snap Inc.

- **Development of Clothing Models**

  The models of clothes pieces are the open-source solution developed in 3D modeling software – Blender, developed by Blender Foundation.

Scope Merge

For prototype demonstration purposes both scopes are merged together. Clothing models rendered in Blender and exported to the Lens Studio, assigned material properties, where the models are projected on the meshed-body model. All operations are performed on the hardware selected for the research.

Table of Content

I. Introduction

1.1 Research Cause

In the 21st century, as predicted by scientific progress, humanity exists side by side with technology. It accompanies humanity throughout every day, whether it is breakfast preparation and traveling to work, or weekend trip to the mall or just spending time at home. If earlier the introduction of any technology into the life of an ordinary consumer was a luxury, nowadays most people can afford it.

At the moment, it is worth paying attention to the gradual development of smart house technologies, which is aimed at facilitating the implementation of daily tasks. The robot vacuums and cleans the floors, the kettle boils water at a snap, and Alexa controls the lighting, music, and temperature in the house. Such technologies were ideally developed to satisfy the needs of people in the mornings and evenings at home when the normalized schedule of the working population is from 9 to 5. However, Covid-19, which happened at the beginning of 2020 and is still in effect, has demonstrated how fragile the established system is. The in-person activities were eliminated from everyday life both from the side of the consumer, who simply cannot go after the products, as well as from the side of the supplier, who cannot produce or supply them.

For this paper, the clothing industry was considered, which, despite its active adaptation to market conditions, during this period showed both its strengths and its flaws. During the COVID-19 period, such a concept as online shopping has become actively spread. Before the pandemic, Marist Poll conducted the study in 2018, and found that 56% of Americans prefer shopping in a physical store than online. However, being able to shop at any time (64%), to find the item easily (62%) and to save time (61%) were all major reasons that could lead to people choosing to shop online[1]. However, after the pandemic BigCommerce and PayPal 2021

consumer spending report found that only 54.5% of Americans preferred shopping in person, and 12.2% didn't care either way. This could just be a temporary drop, but if the trend continues, online shopping could quickly become America's preferred way to shop (Fox, 2023).

That trend allows online stores to rapidly grow and develop, but they do so on older platforms that don't convey the experience a shopper gets in a store – the ability to try on clothes, and that is what the thesis project is aimed at. The current paper will discuss the design and development of the solution that will be able to partially replace the conventional clothing stores in the near future.

1.2 Competition Product Analysis

According to the personal judgement and judgement of numerous retails marketers (Hirschmiller, 2023) and analytics, mirrors with built-in AR technologies can represent such a solution. In general terms it can be described as a smart mirror that can be controlled by the user for the purpose of trying on desired clothes (by using AR technologies to project clothing onto the user's body) and purchasing desired items. Even though the technology is not new, and multiple concepts were presented, similarly to the products in other industries, the difference between smart mirror systems, presented on the market, lies within minor nuances such as interaction style, try-on technology, clothing models, device locations, operational system, development routes, etc.

One of the first prototypes with such technology was presented by LG in 2019 during the CES event in Las Vegas (Prouty, 2019). The ThinQ Smart Mirror allowed the user to create a virtual avatar with personal anthropometric data, try on the variable sized clothing, and purchase it with one touch (Priest, 2020). Smart Mirror presented by MySize three years later, had an almost identical set of characteristics (MySize, 2023), however the major difference between these two

systems is the system's location. LG product was developed for implementation in households, while MySize strictly targeted physical retail spaces. INDE (INDE LLC, 2020) and Zero10 (Zero10, 2023). companies decided to move away from the virtual mannequin idea, and implemented a body tracking cameras in their products (Vyu and AR Mirror), allowing them to project the models of the clothes straight on to the systems user. Selection of the clothing pieces on both systems is carried out by the use of mobile device with preinstalled software. Fashion Mirror by VirtualON (VirtualOn Group, 2023) and AR Mirror from Snap (Perez, 2023) are also based on motion tracking, but unlike the INDE and Zero10, they utilize hand gesture and touch control (respectively) for the interaction with the system, that can be considered a more holistic approach.

Smart wardrobe technology, represented in the research, functions upon the same basic principles as competitors' products, however it is strongly directed towards personalization of the data and processes for the main user of the system, with possibility to extend the systems capability to wardrobe tracking and clothing care.

Company	Product	Interaction	Projection	Location
LG	ThinQ[14]	Touch Screen	Avatar	at-home
MySize	Smart Mirror[6]	Touch Screen	Avatar	in-store
Reactive Reality	Virtual Try-On[21]	Mobile Device	Avatar	in-store
INDE	Vyu[9]	Mobile Device	Body Tracking	at-home
Zero10	AR Mirror[24]	Mobile Device	Body Tracking	in-store
Virtual ON	Fashion Mirror[22]	Hand Tracking	Body Tracking	in-store
Snap	AR Mirror[11]	Touch Screen	Body Tracking	in-store
Smart Wardrobe		Hand Tracking	Body Tracking	at-home

Table 1.1 – Competition Analysis Matrix.

It should be noted that at the time of the research, none of the above-mentioned companies had presented a physical and functional product. Currently, the closest contenders are Zero10-

Tommy Hilfiger (Taylor, 2023) and Snap-Nike collaborations (Basu, 2023), who are the first companies to announce in-store installations in the near future.

II. Operational Modes

The system can be present in four states: one is not operational mode (OFF) and three operational modes (Standby, Settings, Local-OP, and Retail-OP).

Mode						
	№	1	2	3	4	5
	ID	*"OFF"*	*"Standby"*	*"Settings"*	*"Local-Op"*	*"Retail-Op"*
Display Activity - Widgets						
	Weather	X	V	X	X	X
	Date	X	V	X	X	X
	Time	X	V	X	X	X
	Calendar	X	V	X	X	X
	To-Do	X	V	X	X	X
Display Activity - Buttons						
	Settings	X	V	X	X	X
	Retail	X	V	X	X	X
	My Wardrobe	X	V	X	X	V
	Return	X	X	V	V	V
	Clear Selection	X	X	X	V	V
	#-Piece (L/R)	X	X	X	V	?
	Top (L/R)	X	X	X	V	?
	Bottom (L/R)	X	X	X	V	?
	Single-Piece (L/R)	X	X	X	V	?
	Collapse	X	X	X	X	V
	Calendar (I/O)	X	X	V	X	X
	Weather (I/O)	X	X	V	X	X
	To-Do (I/O)	X	X	V	X	X
	Side Conltrol	X	X	V	X	X
	Language	X	X	V	X	X
	Store Selection	X	X	X	X	V
	Category Selection	X	X	X	X	?
	Clothes Selection	X	X	X	X	?
Device Activity						
	Display	X	V	V	V	V
	PC	X	V	V	V	V
	Camera (H)	X	V	V	V	V
	Camera (B)	X	X	X	V	V

Figure 2.1 – Operational Modes Matrix

2.1 OFF

The system is fully OFF, no power is supplied. Can only be used as a regular mirror, without disturbing the design of the interior. By interaction with the physical switch, a user can control the power state and activate the mirror by it into the Standby Mode.

2.2 Standby

The system is ON and displays the basic information in the form of widgets, which depict basic information such as Date, Time, Weather, Calendar, and To-Do list, that can influence the user's choice of the outfit for the day. Widgets (Figure 2.2 and 2.3) cannot be interacted with directly through the system and draw the information from the phone applications (except Date and Time).

Figure 2.2 – Standby (without User)

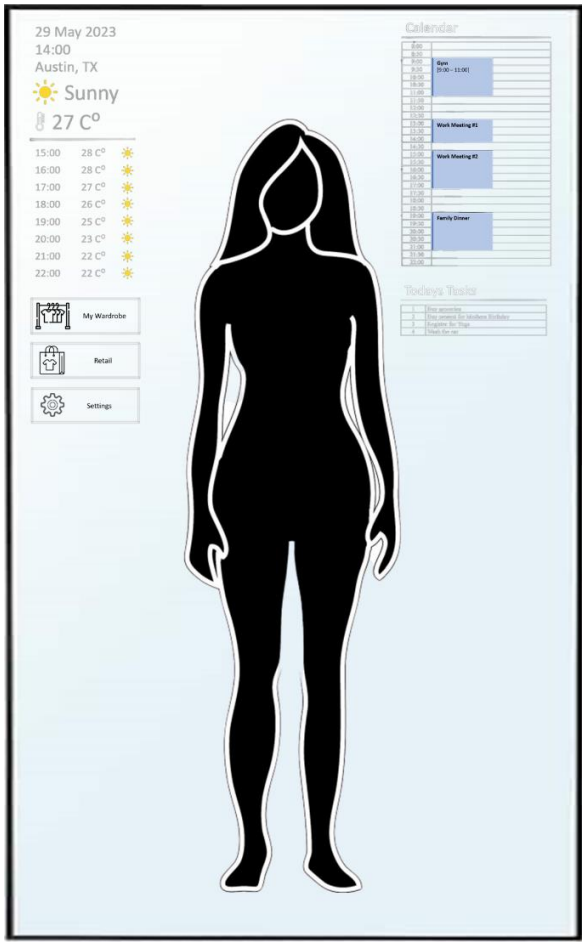


Figure 2.3 – Standby (with User)

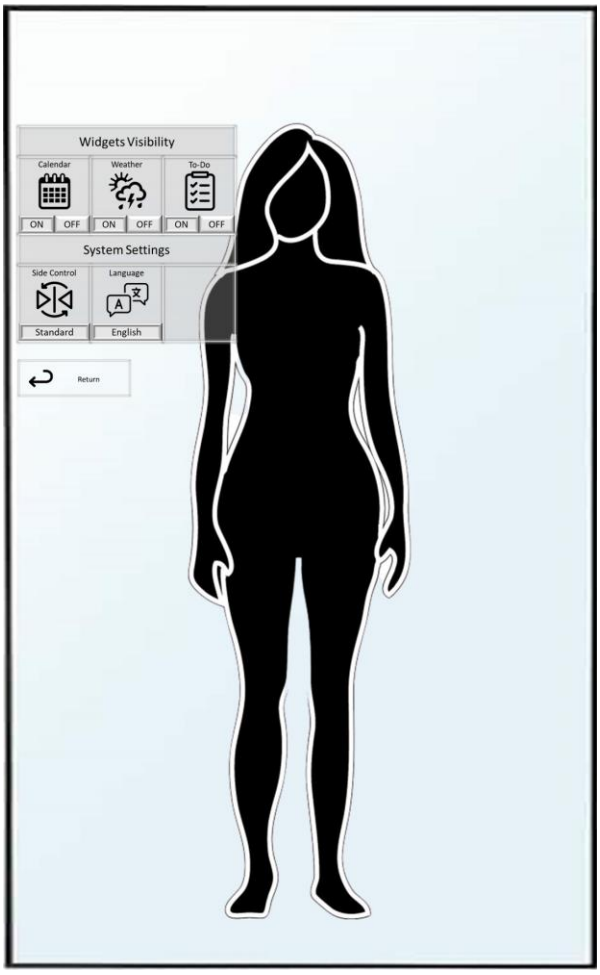


Figure 2.4 – Settings

Unlike widgets, the buttons located on the screen can be interacted with directly, 3 of which are located on the screen. The Setting button, which is only available in standby mode, gives the user an opportunity to control the visibility of each widget, switch sides for the information displayed on the screens, and select the system language. My Wardrobe and Retail buttons are responsible for transferring the user into operational modes where he/she can try on different styles of clothing. While system is remains in Standby mode, computational hardware, and hand-gesture recognition camera are active, however the body tracking camera is disabled.

2.3 Settings

In the Settings mode (Figure 2.4) , user gets access to the essential settings of the system, which are separated into two groups. Widgets Visibility controls the showing of calendar, weather, and to-do list on the main screen, and can either be turned on or off. The system settings section gives user controls over the language of the system, that can be switched by clicking on the same button and control over the side on which the button/widget windows appear in all modes (standard or flipped).

2.4 My Wardrobe (Local-OP)

In My Wardrobe mode, the system automatically activates the second camera used for body tracking and allows the used to try on all clothes stored in the locally. That local database gets filled with new items upon the successful online purchase. The purpose of that mode is to ease the daily clothing selection without spending time physically trying on clothes, as well as to keep track of the existing clothes in the wardrobe. All previously mentioned widgets are absent on the screen in local-op, instead the user is presented with the area in which the clothes can be scrolled through and selected. It can be done by using the numerous buttons that control the clothing type selection (Single-Piece and Mutli-Piece) and the clothing model selection within the types. The buttons for returning to home screen and clearing the clothes selection are also displayed on the screen.

Figure 2.5 – Local-OP (multi-piece)

Figure 2.6 – Local-OP (single-piece)

2.4 Retail (Retail-OP)

In Retail mode the user gets access to shopping with direct sellers and re-sellers that are registered in the system. Store selection section, that appears after entering Retail mode, allows the user to coordinate between the online stores. Each store will have freedom in rendering their own store page, but to reach the fluency of customers in the smart-mirror experience, they will follow the standard template. The top part of the screen is dedicated to the company logo, while the area on the side is dedicated to Store Selection (Figure 2.7), Categories (Figure 2.8), Clothing Selection (Figure 2.9), and any following breakdowns dictated by vendor.

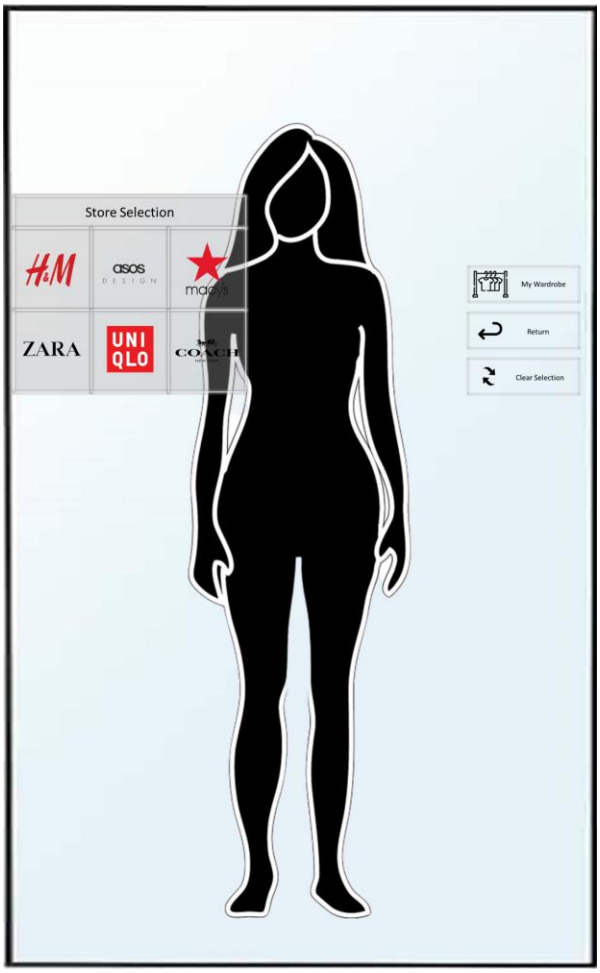


Figure 2.7 – Retail-OP (stores selection)

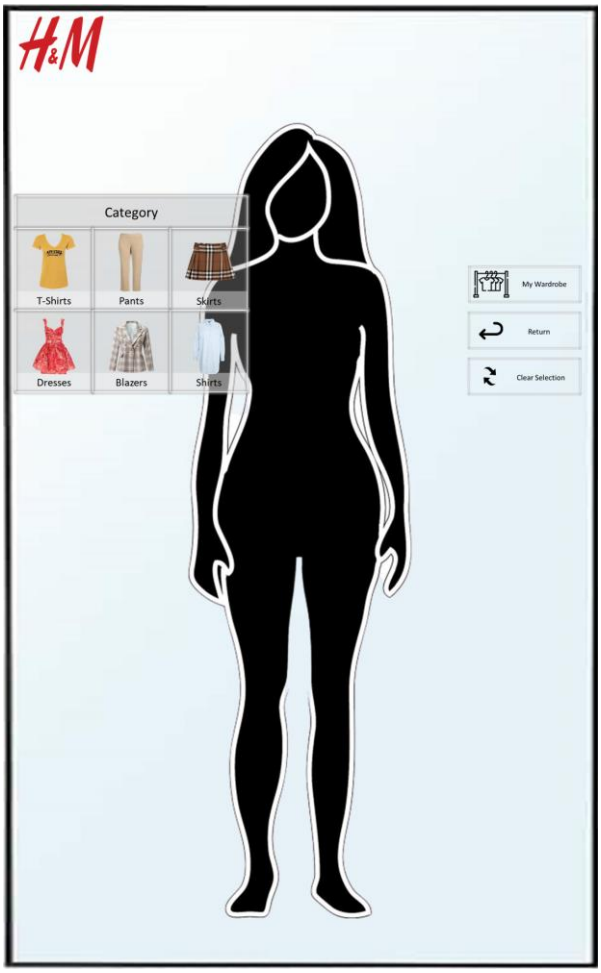


Figure 2.8 – Retail-OP (category selection)

Figure 2.9 – Retail-OP (clothes selection)

System functionality does not differ much from Local-OP, both tracking cameras are active, and allow the user to try on all clothing range presented in store. However, the system will require a network connection through Wi-Fi or LAN cabling to navigate through the online stores.

Similarly, to the Local-OP mode, Return and Clear Selection buttons can be found on the screen, with an addition of the MyWardrobe button that allows the user to switch into Local-OP and try on the previously and freshly purchased clothes.

The last step of the selection breakdown is accompanied with collapse button, that allows the user to maximize the free area on the mirror, and try-on potential clothing with no obstructions.

III. Operational Logic

3.1 Hand Gestures

The Smart Mirror system is designed to be fully controlled by hand tracking and gestures recognition. Such an approach eliminates the need to touch the mirroring surface, consequently, leaving dirt and markings on it. To fully interact with the system, the user is only required to use two gestures: one for navigation (Figure 3.1) and the other for selection (Figure 3.2).

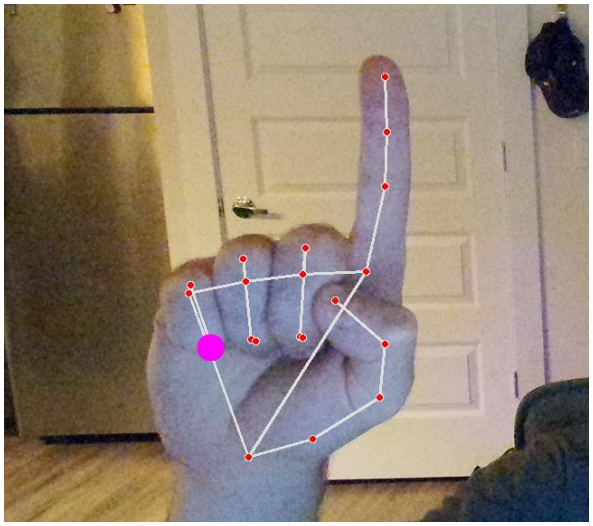


Figure 3.1 – Navigation Gesture

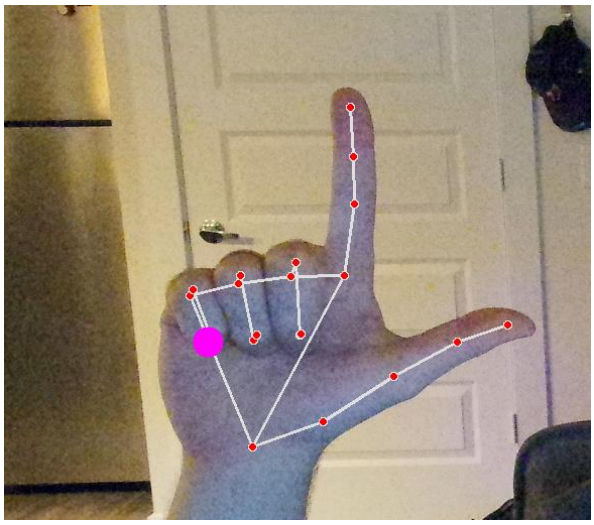
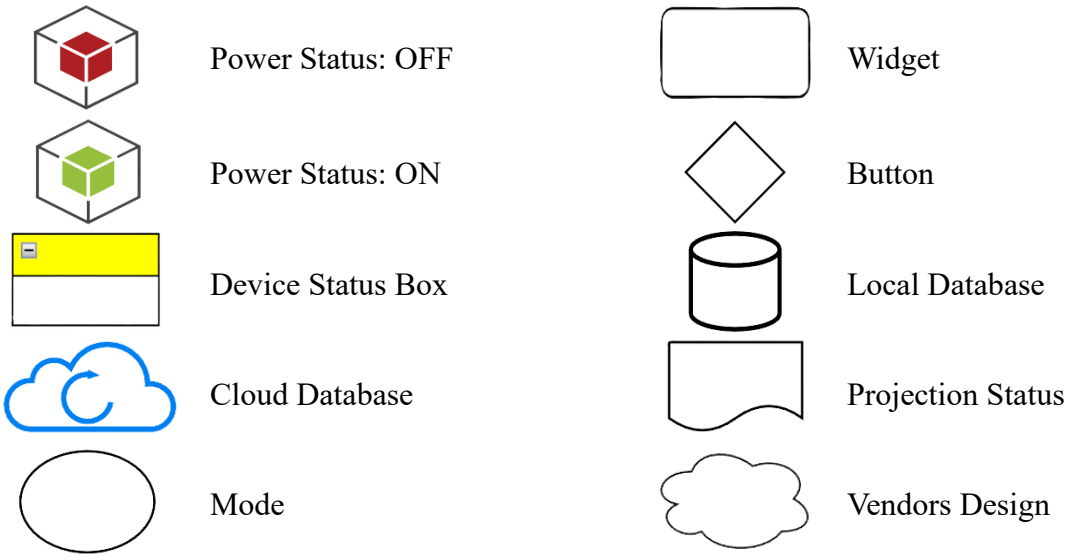


Figure 3.2 – Selection Gesture

3.2 Flow-Chart

The logic of the system's functionality is described in Figure 3.3, in the form of the flow-chart, that marks out several important components apart from logic flow, such as Device Status at all modes, Database draws, and Vendors scope (design of the personal retail space).

Flow-Chart Legend:



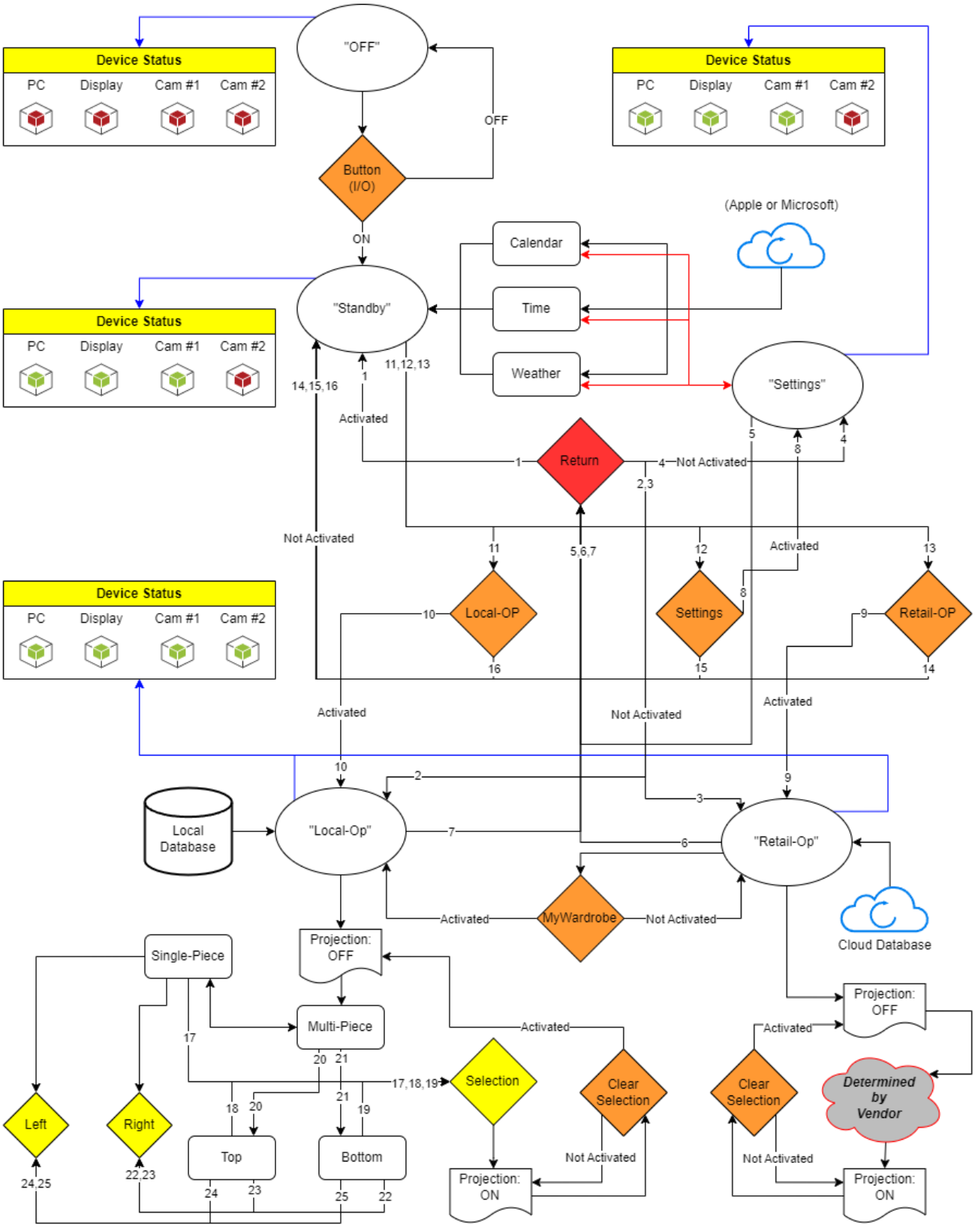


Figure 3.3 – Operational Flow-Chart

IV. Electrical Design

4.1 Single-Line Diagram

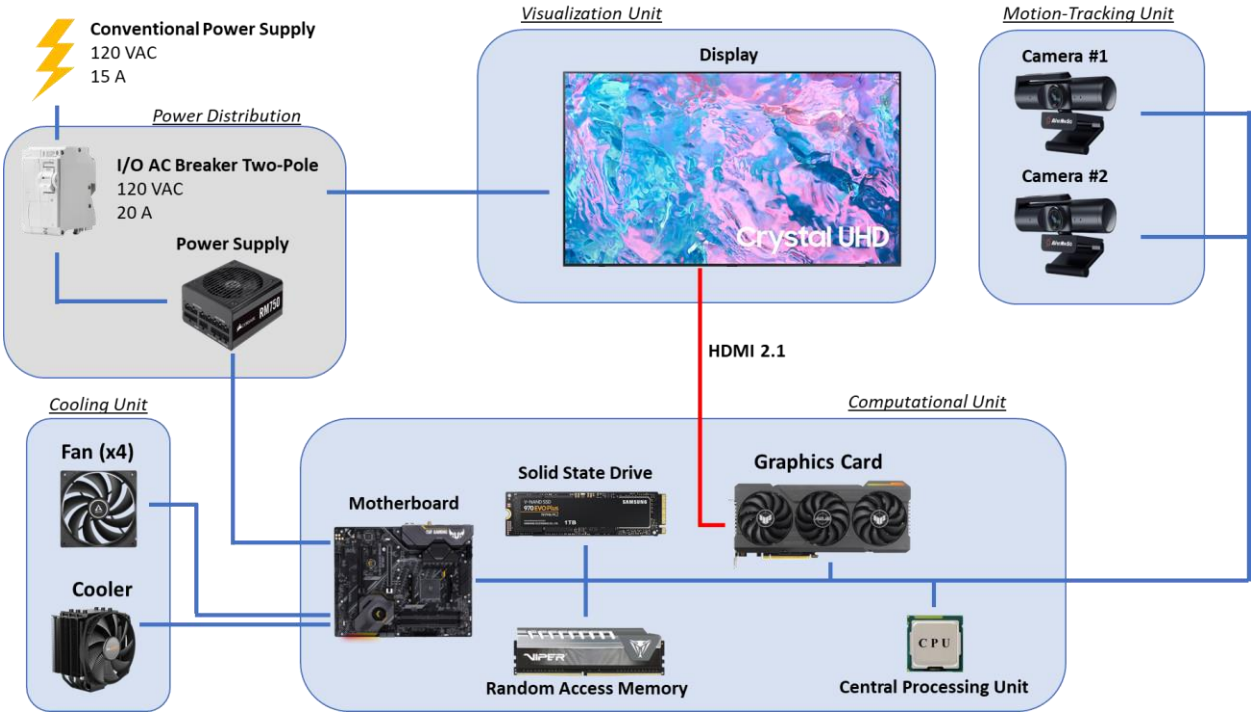


Figure 4.1 – Single-Line Electrical Diagram

The system is designed to be powered from the regular U.S. household wall outlet that outputs 120VAC at 20A. The breaker unit serves 3 purposes, it protects the system in the event of overload, acts as an I/O button to control the power status of the system, and branches the power distribution to the computational and visualization units. Power supply is used to convert AC to DC and properly power on the computational unit, and consequently cooling and motion-tracking units. The cooling unit consists of 4 fans installed to intake the air at the bottom (where the temperature is the lowest) and exhaust the warm air from the system at the top, as well as the CPU cooler to prevent the processor from overheating. Computational unit is equipped with Solid State Drive and RAM acting as a Local Database for models' storage and retrieval, CPU to provide

enough computational power for the system, Graphics Card to display the information to visualization unit, and motherboard as a point of tie-in, that additionally provides the network connection through Wi-Fi or LAN cable. The Motion-Tracking unit utilizes 2 separate cameras: one for hand tracking and the other for body tracking. The visualization unit consists of the TV screen connected to the motherboard through HDMI cable.

4.2 Electrical Bill of Materials

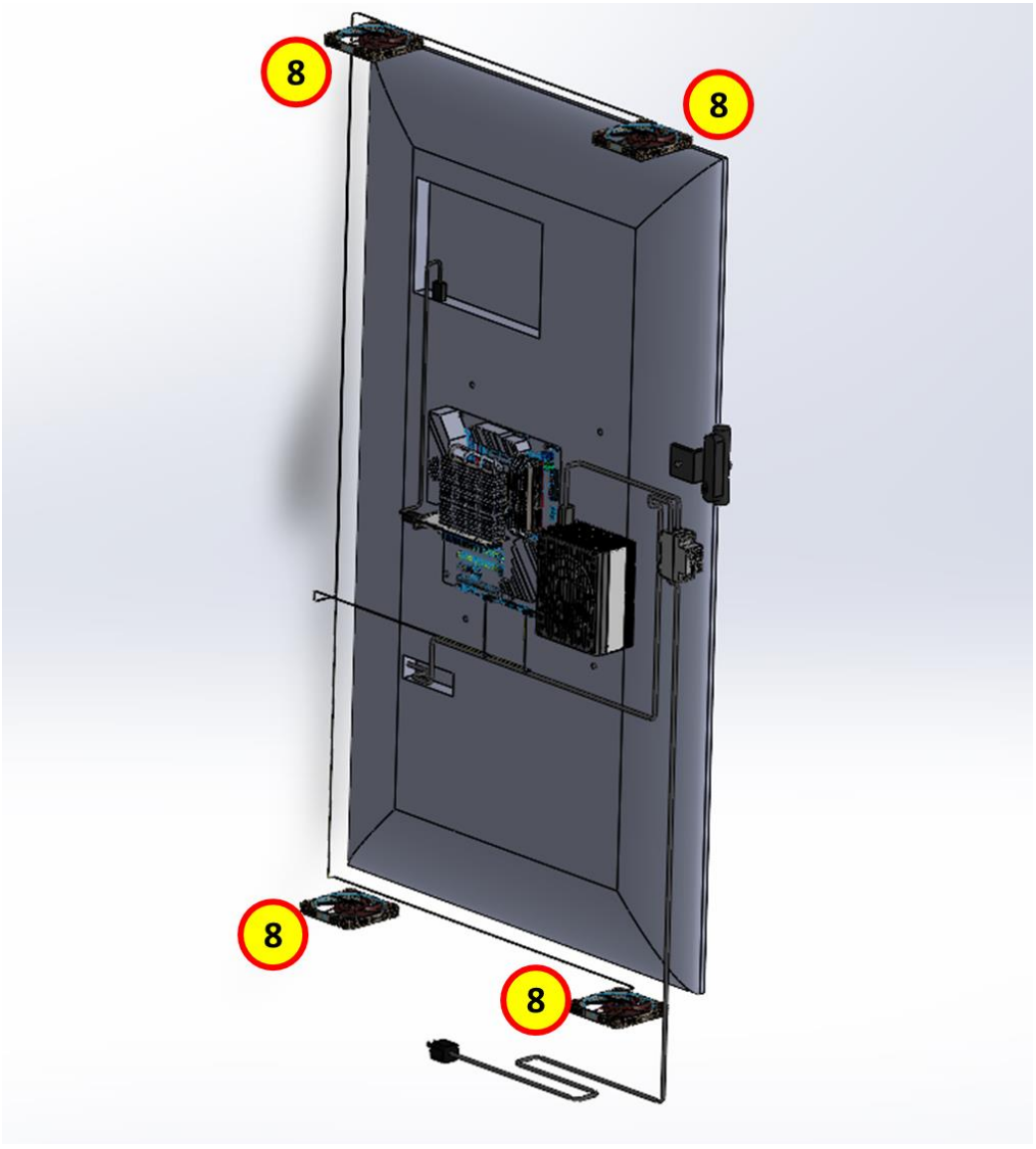


Figure 4.2 – Electrical CAD

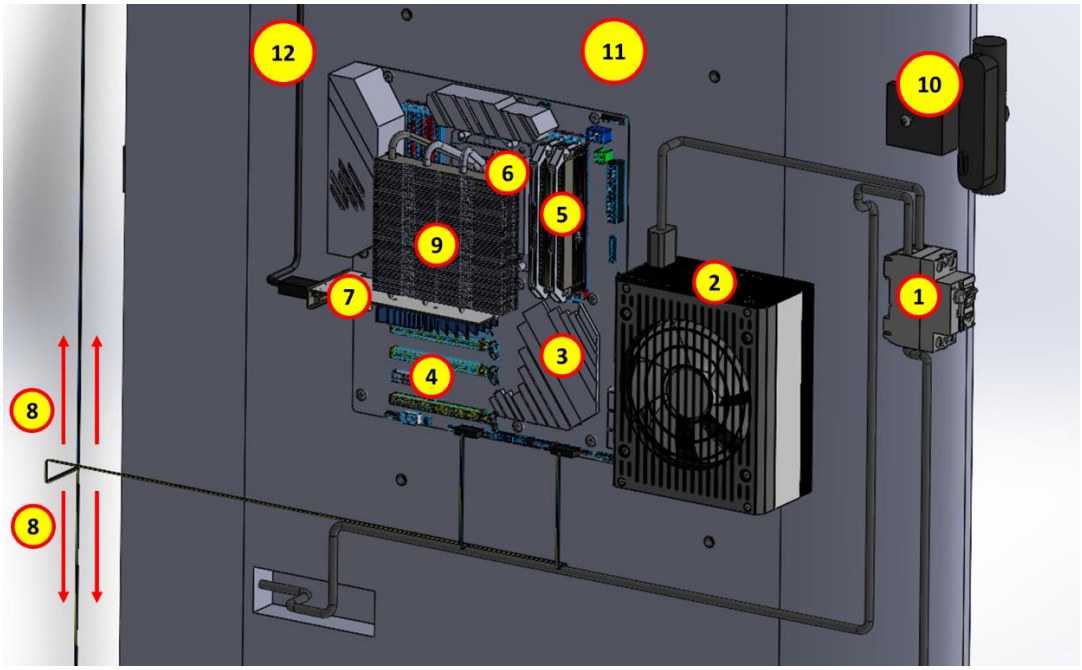


Figure 4.3 – Computational and Cooling Units CAD

Item	Part	Part #	Manufacturer	Description	Qty.	Unit Cost	Sub-Cost
Power Distribution							
1	Circuit Breaker	78477644676	Leviton	LB225-T	1	$ 16.98	**$ 16.98**
2	Power Supply	CP-9020231-NA	Corsair	Series RM750	1	$ 116.99	**$ 116.99**
Computational							
3	Motherboard	6422283	Asus	ROG STRIX B550-F	1	$ 182.99	**$ 182.99**
4	Solid State Drive	MZ-V7S1T0BAM	Samsung	970 EVO Plus: 1TB	1	$ 54.99	**$ 54.99**
5	Random Access Memory	CMK16GX4M2D3600C18	Corsair	Vengeance LPX 16GB (2 x 8GB)	1	$ 41.99	**$ 41.99**
6	Central Processing Unit	00-100000457BOX	AMD	AMD - Ryzen 5 - 5500	1	$ 99.00	**$ 99.00**
7	Graphics Card	GV-N1030D4-2GL	Gigabyte	Nvidia GeForce GT1030	1	$ 69.99	**$ 69.99**
Cooling							
8	Cooling Fan	NF-A12x15 FLX	Noctua	Quiet Slim Fan, 3-Pin (120x15mm)	4	$ 21.95	**$ 87.80**
9	CPU Cooler	NH-L12	Noctua	Ghost S1 Edition, Low Profile	1	$ 54.59	**$ 54.59**
Motion-Tracking							
10	WebCamera	795522966735	AverMedia	PW513	1	$ 100.99	**$ 100.99**
11	Camera #2	-	-	-	1		**$** -
Visualization							
12	Display	UN65TU7000FXZA	Samsung	Class 7 Series	1	$ 450.00	**$ 450.00**
13	HDMI Cable	1P3FTGO21LD	SatelliteSale	Digital Ultra High-Speed	1	$ 10.95	**$ 10.95**
						Total Cost:	**$ 1,276.31**

Figure 4.4 – Electric Bill of Materials.

V. Mechanical Design

5.1 Components Selection Criteria

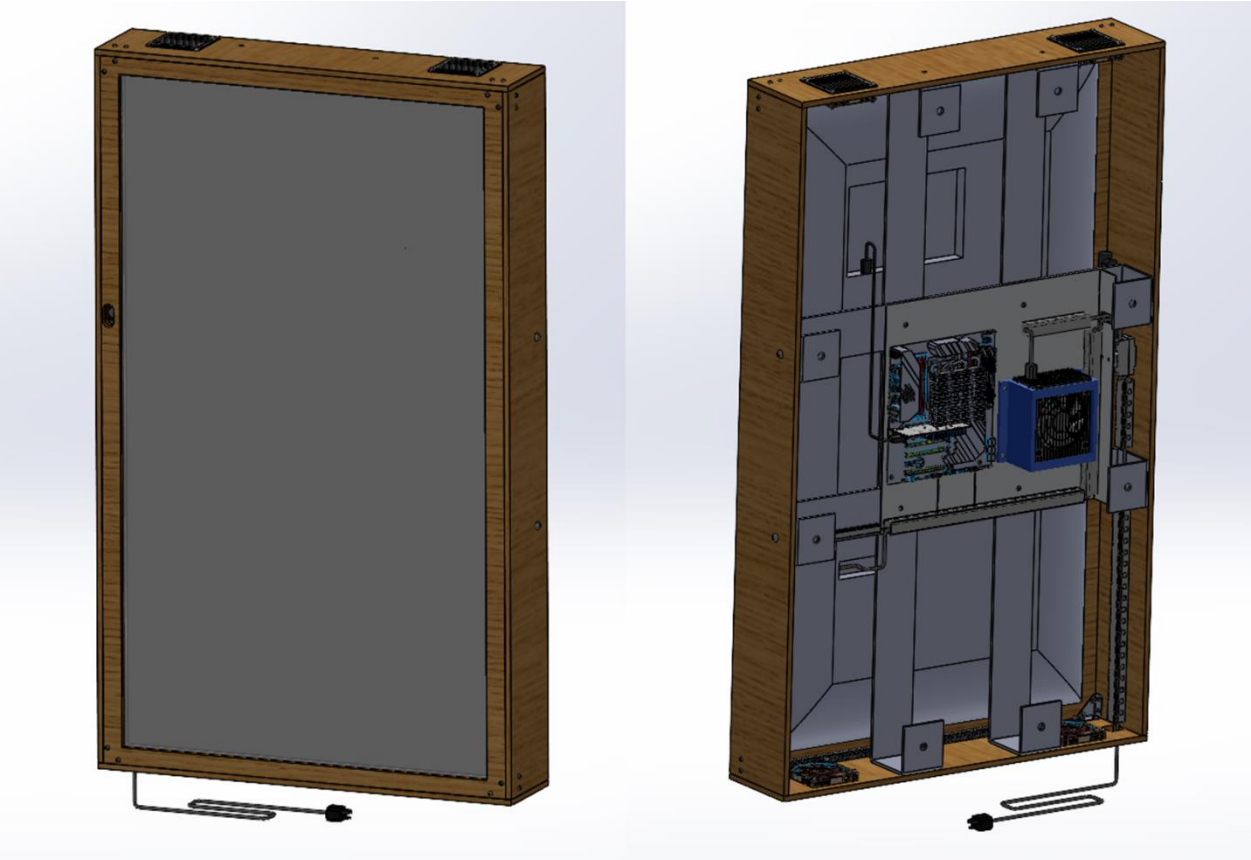


Figure 5.1 – Smart Mirror CAD Design

Mechanical design of the system consists of 3 major parts that can be divided by materials (apart from electrical elements):

1. Metal Framing
2. Wooden Framing
3. Reflective Surface

Component selection for each section was based on 4 criteria of sustainable material selection guidelines described by the Institution of Structural Engineers (Sustainability Panel, 2019):

1. **Manufacturing Design Efficiency (MDE)** – describes the volume percentage of the raw material usage in the final product compared to stock purchased item.

MDE (Volume):

$$V_{MDE} = \frac{V_{Raw} - V_{Cut}}{V_{Raw}} \times 100\% \quad \textbf{(5.2)}$$

Cut-Out (Volume):

$$V_{Cut} = \sum (A \times h) \quad \textbf{(5.3)}$$

2. **Fitness for Purpose** – describes the ability of the fixture to not only meet the necessary structural performance criteria, but also considers the amount of required maintenance, can accommodate future adaptation, and environmental impact during its lifetime. Evaluated on 1–4-point basis, with a point for each successful criterion.
3. **Recyclable Content** – described as the percentage of material that can be recycled after the end of the useful life.
4. **End of Life** – describes the treatment method of the material after the demolition / disposal.

5.2 Metal Framing

The Metal Framing of the Smart Mirror consists of five independent components: two horizontal steel bars, two vertical steel bars, and a single aluminum sheet, interconnected with steel fasteners.

SS_Frame_Hrz (Figure 5.5 and 5.6): is a rectangular T304 stainless-steel bar the size 60" x 4" x 1/4" with the following cut-outs:

Fixture:	Reason:	Amount:
Ø16.50 mm hole	Wall mount	2
Ø10.50 mm hole	Wooden frame and screen mount	4
Ø5.50 mm hole	Camera mount	1
	V_{Cut}	**5,065.82 mm^3**

Table 5.4 – Horizontal Bar Cut-Outs

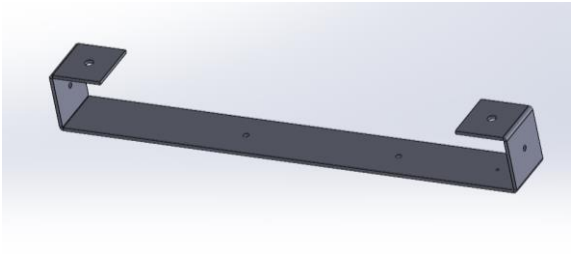


Figure 5.5 – SS_Frame_Hrz (Folded)

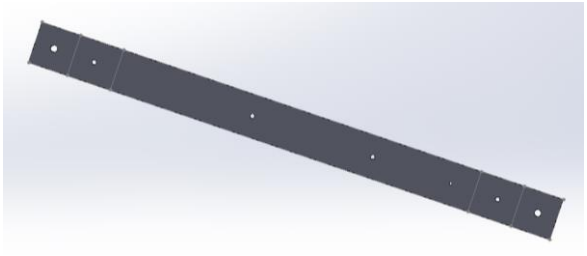


Figure 5.6 – SS_Frame_Hrz (Unfolded)

SS_Frame_Vrt (Figure 5.8 and 5.9): is a rectangular T304 stainless-steel bar the size 77" x 4" x 1/4" with the following cut-outs:

Fixture:	Reason:	Amount:
Ø16.50 mm hole	Wall mount	2
Ø10.50 mm hole	Wooden frame mount	4
	V_{Cut}	**4,914.96 mm^3**

Table 5.7 – Vertical Bar Cut-Outs

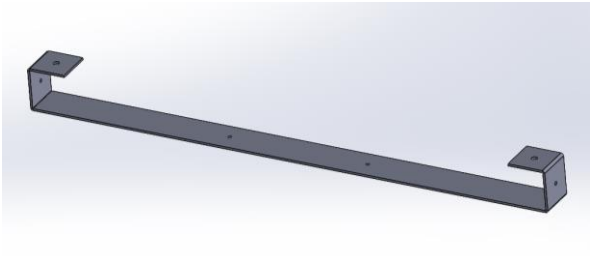


Figure 5.8 – SS_Frame_Vrt (Folded)

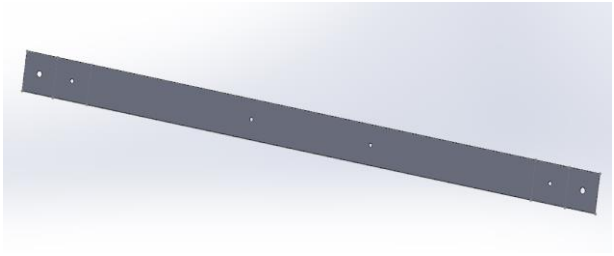


Figure 5.9 – SS_Frame_Vrt (Unfolded)

Cmp_Mount_Plate (Figure 5.11 and 5.12): is a 3003-aluminum sheet the size 24" x 20" x 1/8" with the following cut-outs:

Fixture:	Reason:	Amount:
Ø10.50 mm hole	Screen mount	4
Ø6.3 mm hole	DIN Rail / Breaker mount	2
Ø5.50 mm hole	Power Supply bracket mount	4
Ø4.50 mm hole	Motherboard mount	9
778.5 mm^2 cut-through	Wiring feed	1
	V_{Cut}	**4,525.57 mm^3**

Table 5.10 – Vertical Bar Cut-Outs

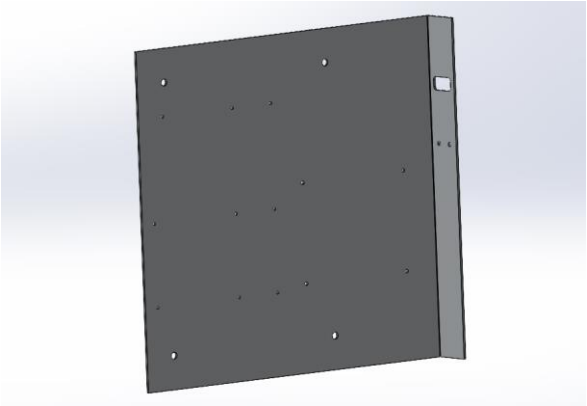


Figure 5.11 – Cmp_Mount_Plate (Folded)

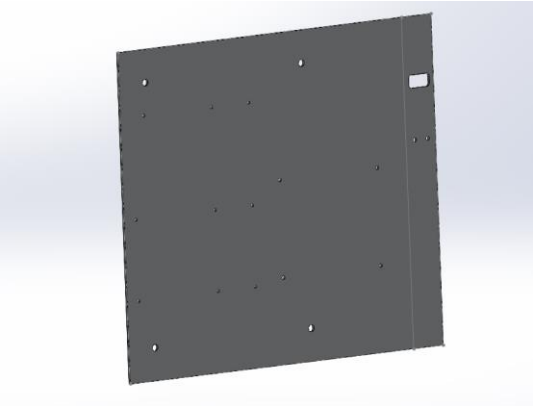


Figure 5.12 – Cmp_Mount_Plate (Unfolded)

The steel framing serves the main purpose of holding the components of the system together and attaching it to the wall. T304 stainless steel is resistant to corrosion and requires minimal maintenance especially indoors, it has moderate forming and machining qualities and can be adapted to any revisions of the design if required. In addition, stainless steel is 100% recyclable and does not produce any toxic run-offs during production. Therefore, accounting for the fact that half of today's steel has been sourced from scrap, it can be counted as an absolute green material that can be reused after the useful lifecycle of a product (Ulbrich, 2020).

The aluminum plate in the design allows for most electrical components to be attached to the main structure. 3003 Grade is corrosion resistant, highly durable, and possesses an excellent formability property. Additionally, it weighs 10x less than T304 stainless steel (per unit of area) (TW Metals, 2019), while perfectly supporting the weight of the attached components: motherboard with all elements, circuit breaker, and power supply bracket. Also, aluminum is 100% recyclable and reusable afterwards (The Aluminum Association, 2021), which makes it a preferred selection of material in the design.

CAD Part Name	L (mm)	W (mm)	Th (mm)	V_Tot (mm^3)	V_Cut (mm^3)	MDE
SS_Frame_Hrz	1524	101.6	6.35	983,223.84	5,065.82	99.48%
SS_Frame_Hrz	1524	101.6	6.35	983,223.84	5,065.82	99.48%
SS_Frame_Vrt	1955.8	101.6	6.35	1,261,803.93	4,914.96	99.61%
SS_Frame_Vrt	1955.8	101.6	6.35	1,261,803.93	4,914.96	99.61%
Cmp_Mount_Plate	609.6	508	3.175	983,223.84	4,525.57	99.54%
					Metal Frame Total MDE:	**99.55%**

Table 5.13 – Metal Frame MDE

5.3 Wooden Framing

The Wooden Framing of the Smart Mirror consists of 6 independent components: one internal and one external front facias, and four sides (left, right, top, bottom).

Wood_Facia_Ext (Figure 5.16): is a Veneered MDF panel the size 60" x 36" x 1/2" with the following cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Facia mount	8
*863,683.04mm^2 cut-through	Screen visibility	1
46,000 mm^2 cut at 4mm	Reflective surface mount	1
115.87 mm^2 cut-through	Camera visibility	1
	V_{Cut}	**11,156,660.00 mm^3**

**Wasteful area of 863,683.04mm^2 is calculated with account that cut-out material is used on TS and BS pieces.*

Table 5.14 – Front External Facia Cut-Outs

Wood_Facia_Int: is the mirrored replica of ***Wood_Facia_Ext*** with the identical cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Facia mount	8
*863,683.04mm^2 cut-through	Screen visibility	1
46,000 mm^2 cut at 4mm	Reflective surface mount	1
115.87 mm^2 cut-through	Camera visibility	1
	V_{Cut}	**11,156,660.00 mm^3**

**Wasteful area of 863,683.04mm^2 is calculated with account that cut-out material is used on TS and BS pieces.*

Table 5.15 – Front Internal Facia Cut-Outs

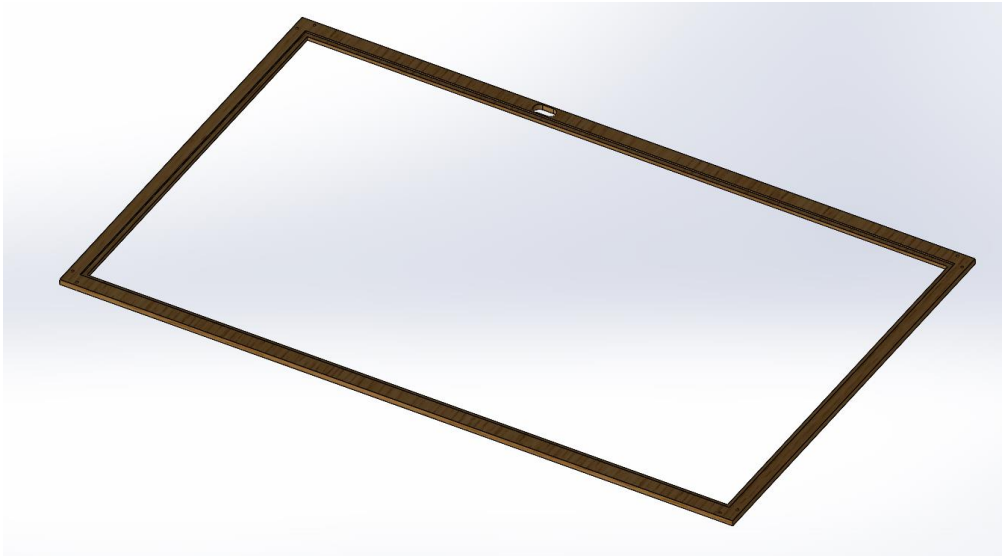


Figure 5.16 – External Wooden Facia

Wood_Facia_LS (Figure 5.18): is a Veneered MDF panel the size 60" x 8" x 1/2" with the following cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Facia interconnection	4
Ø10.50 mm hole	Facia mount	2
	V_{Cut}	**3,406.31 mm^3**

Table 5.17 – LS Facia Cut-Outs

Figure 5.18 – LS Facia

Wood_Facia_RS (Figure 5.20): is a Veneered MDF panel the size 60” x 8” x 1/2” with the following cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Facia interconnection	4
Ø10.50 mm hole	Facia mount	2
1,615.25 mm^2 cut-through	Breaker access	1
	V_{Cut}	**23,919.98 mm^3**

Table 5.19 – RS Facia Cut-Outs

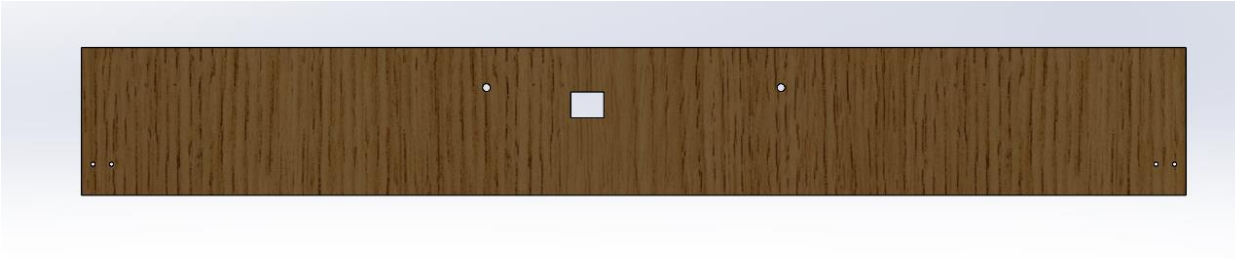


Figure 5.20 – RS Facia

Wood_Facia_TS (Figure 5.22): is a Veneered MDF panel the size 37” x 8” x 1/2” with the following cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Fan guard and facia interconnection	12
Ø10.50 mm hole	Facia mount	2
Ø115.00 mm hole	Fan air tunnels	2
	V_{Cut}	**269,646.95 mm^3**

Table 5.21 – TS Facia Cut-Outs

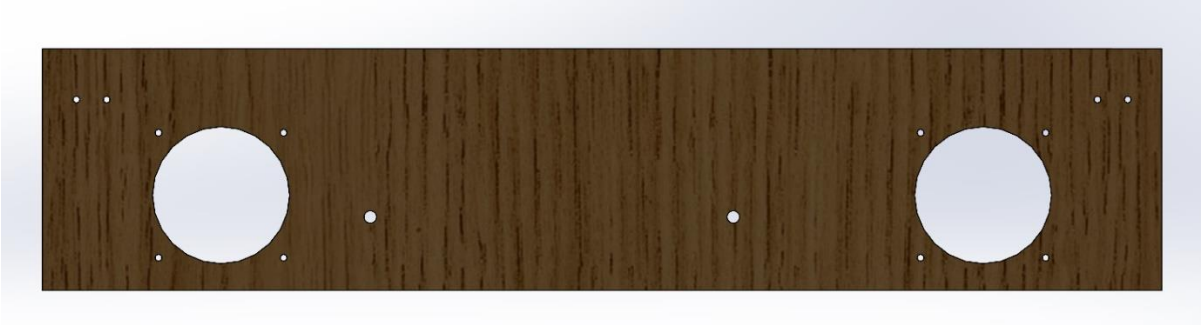


Figure 5.22 – TS Facia

Wood_Facia_LS (Figure 5.24): is a Veneered MDF panel the size 37” x 8” x 1/2” with the following cut-outs:

Fixture:	Reason:	Amount:
Ø5.50 mm hole	Fan guard and facia interconnection	12
Ø10.50 mm hole	Facia mount	2
Ø115.00 mm hole	Fan air tunnels	2
1,430.15 mm^2 cut through	Power wiring routing tunnel	1
	$\boldsymbol{V_{Cut}}$	**287,809.86 mm^3**

Table 5.23 – BS Facia Cut-Outs

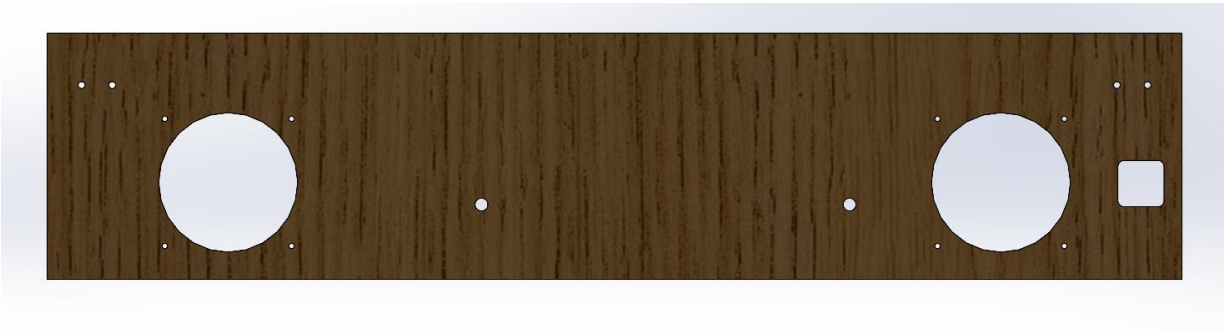


Figure 5.24 – BS Facia

All facia components are expected to be produced from the Veneered MDF (Medium Density Fiberboard) panels. They do not carry any load, the only components connected to it are wire duct and cooling fans, therefore it only carries decorative character. Also, MDF material is easy to work on, and any decorative features can be applied to it (Suso, 2020). However, the main advantage of this material is its sustainability aspect. MDF is engineered wood which is produced

from recycled materials such as fibers, shavings, and other wood residuals. Even though MDF is not recyclable itself (due to being the last stage), it is biodegradable, and doesn't produce landfill due to its decomposition properties (Rinkesh, 2022).

CAD Part Name	L (mm)	W (mm)	Th (mm)	V_Tot (mm^3)	V_Cut (mm^3)	MDE
Wood_Facia_Ext	1524	914.4	12.7	17,698,029.12	11,156,660.00	36.96%
Wood_Facia_Int	1524	914.4	12.7	17,698,029.12	11,156,660.00	36.96%
Wood_Facia_LS	1524	203.2	12.7	3,932,895.36	3,406.31	99.91%
Wood_Facia_RS	1524	203.2	12.7	3,932,895.36	23,919.98	99.39%
Wood_Facia_TS	939.8	203.2	12.7	2,425,285.47	269,646.95	88.88%
Wood_Facia_BS	939.8	203.2	12.7	2,425,285.47	287,809.86	88.13%
					Wooden Facia Total MDE:	**75.04%**

Table 5.25 – Wooden Frame MDE

5.4 Reflective Surface

Single piece reflective surface contains no holes or cut-outs; therefore, it does not contain any material waste. To fix the mirror in place, without cutting the through holes, this cut-to-size component of the smart mirror system is cramped between Wooden Internal and External Facias in the dedicated trim.

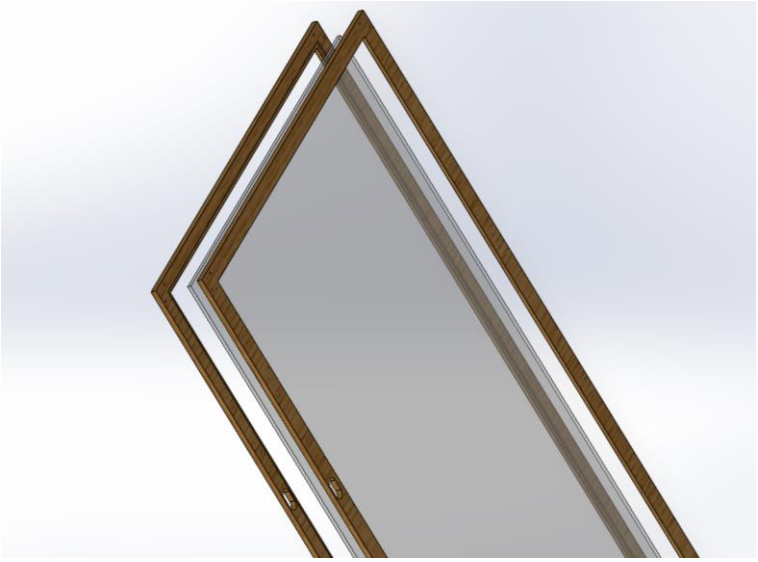


Figure 5.26 – Reflecting Surface

CAD Part Name	L (mm)	W (mm)	Th (mm)	V_Tot (mm^3)	V_Cut (mm^3)	MDE
Reflective_Srfc	1470	850	8	9,996,000.00	-	100.00%
					Reflective Material Total MDE:	**100.00%**

Table 5.27 – Reflective Surface MDE

Reflective surface is expected to be produced from the Two-Way Acrylic Mirror sheet. It is less fragile, less expensive, and less heavy material compared to traditional two-way mirrors. Even though it may cause minor deflection in the users' reflection (Built by Az, 2018) while the system is in OFF mode, it is fully transparent when the screen turns on, which is the main operational mode. In addition, acrylics is a fairly sustainable material, especially compared to classic mirrors. Some portions of acrylics can be recycled, it is lighter and therefore cleaner to transport, it is very resilient and is expected to have a long life cycle and minimum maintenance. Nowadays, some companies have the ability to produce acrylic sheets from previously recycled material, with around 30-50% of usage (Stanfield, 2021). However, it is very hard to find such companies, and due to the lack of biodegradability, it can be considered a landfill.

Structure	Element Shape	CAD Part Name	Material	MDE	Fitness for Purpose	Recyclable Content	End of Life
Frame (Inner)	Flat Bar	*SS_Frame_Hrz*	T304 Stainless Steel	99.48%	4	100%	Reusable
	Flat Bar	*SS_Frame_Hrz*	T304 Stainless Steel	99.48%	4	100%	Reusable
	Flat Bar	*SS_Frame_Vrt*	T304 Stainless Steel	99.61%	4	100%	Reusable
	Flat Bar	*SS_Frame_Vrt*	T304 Stainless Steel	99.61%	4	100%	Reusable
	Sheet	*Cmp_Mount_Plate*	3003-H14 Aluminum	99.54%	4	100%	Reusable
Frame (Outer)	Panel	*Wood_Facia_Ext*	Veneered MDF	36.96%	4	0%*	Biodegradable
	Panel	*Wood_Facia_Int*	Veneered MDF	36.96%	4	0%*	Biodegradable
	Panel	*Wood_Facia_LS*	Veneered MDF	99.91%	4	0%*	Biodegradable
	Panel	*Wood_Facia_RS*	Veneered MDF	99.39%	4	0%*	Biodegradable
	Panel	*Wood_Facia_TS*	Veneered MDF	88.88%	4	0%*	Biodegradable
	Panel	*Wood_Facia_BS*	Veneered MDF	88.13%	4	0%*	Biodegradable
Reflective Surface	Panel	*Reflective_Srfc*	Two Way Acrylic Mirror	100.00%	3	50%	Reusable (Max)
			Total:	**87.33%**	**98%**	**91.67%**	

** Last life cycle of the material*

Table 5.28 – Sustainable Materials Selection Matrix

VI. Bill of Materials

Item	Part	Part #	Manufacturer / Vendor	Description	Qty.	Unit Cost	Sub-Cost
Electrical Components							***$ 1,287.26***
1	Circuit Breaker	78477644676	Leviton	LB225-T	1	$ 16.98	**$ 16.98**
2	Power Supply	CP-9020231-NA	Corsair	Series RM750	1	$ 116.99	**$ 116.99**
3	Motherboard	6422283	Asus	ROG STRIX B550-F	1	$ 182.99	**$ 182.99**
4	Solid State Drive	MZ-V7S1T0BAM	Samsung	970 EVO Plus: 1TB	1	$ 54.99	**$ 54.99**
5	Random Access Memory	CMK16GX4M2D3600C18	Corsair	Vengeance LPX 16GB (2 x 8GB)	1	$ 41.99	**$ 41.99**
6	Central Processing Unit	00-100000457BOX	AMD	AMD - Ryzen 5 - 5500	1	$ 99.00	**$ 99.00**
7	Graphics Card	GV-N1030D4-2GL	Gigabyte	Nvidia GeForce GT1030	1	$ 69.99	**$ 69.99**
8	Cooling Fan	NF-A12x15 FLX	Noctua	Quiet Slim Fan, 3-Pin (120x15mm)	4	$ 21.95	**$ 87.80**
9	CPU Cooler	NH-L12	Noctua	Ghost S1 Edition, Low Profile	1	$ 54.59	**$ 54.59**
10	WebCamera	795522966735	AverMedia	PW513	1	$ 100.99	**$ 100.99**
11	Camera #2	-	-	-	1		**$ -**
12	Display	UN65TU7000FXZA	Samsung	Class 7 Series	1	$ 450.00	**$ 450.00**
13	HDMI Cable	1P3FTGO21LD	SatelliteSale	Digital Ultra High-Speed	1	$ 10.95	**$ 10.95**
Mechanical Components							***$ 1,566.31***
14	Stainless Steel Flat	F5144	MetalsDepot	52" x 4" x 1/4"	2	$ 104.45	**$ 208.90**
15	Stainless Steel Flat	F5145	MetalsDepot	77" x 4" x 1/4"	2	$ 225.32	**$ 450.64**
16	Aluminum Plate	S318	MetalsDepot	24" x 20" x 1/8"	1	$ 69.12	**$ 69.12**
17	Button Head Screw	92095A127	McMaster	M5 x 0.8 x 15mm	5	$ 0.17	**$ 0.85**
18	Button Head Screw	92095A416	McMaster	M10 x 1.5 x 30mm	8	$ 1.48	**$ 11.80**
19	Steel Locknut	93625A350	McMaster	M10 x 1.5 x 10mm	8	$ 0.62	**$ 4.96**
20	Corner Bracket	1088A41	McMaster	2" x 18 Screw	4	$ 4.68	**$ 18.72**
21	Steel Locknut	93625A200	McMaster	M5 x 0.8 x 5mm	24	$ 0.88	**$ 21.12**
22	Button Head Screw	97763A458	McMaster	M5 x 0.8 x 20mm	16	$ 0.34	**$ 5.44**
23	Button Head Screw	53GJ20	Grainger	M5 x 0.8 x 35mm	8	$ 0.25	**$ 2.00**
24	Phillips Head Screw	92000A215	McMaster	M4 x 0.7 x 5mm	9	$ 0.86	**$ 7.74**
25	DIN3 Rail	8961K18	McMaster	D:15mm x 50mm	1	$ 0.50	**$ 0.50**
26	Phillips Head Screw	90116A233	McMaster	M4 x 0.7 x 40mm	16	$ 0.30	**$ 4.80**
27	Steel Nut	90592A090	McMaster	M4 x 0.7 x 3.2mm	16	$ 0.03	**$ 0.53**
28	Veneered MDF Panel	-	MDFDirect	60" x 36" x 1/2"	2	$ 116.53	**$ 233.06**
29	Veneered MDF Panel	-	MDFDirect	60" x 8" x 1/2"	2	$ 28.78	**$ 57.56**
30	Two-Way Acrylic Mirror S	-	Plasticstocklist	58 7/8" x 33 15/32" x 1/4"	1	$ 372.50	**$ 372.50**
31	Fan Shielded Guard	9SIARK0FU04707	NewEgg	120mm x 120mm	1	$ 18.50	**$ 18.50**
32	Wire Duct with Cover	7578K43	McMaster	1in x 1in x 6ft	1	$ 31.03	**$ 31.03**
33	Wire Duct with Cover	7578K41	McMaster	5/8in x 1/2in x 6ft 1/2in	1	$ 28.54	**$ 28.54**
34	Wire Duct with Cover	7578K41	McMaster	5/8in x 1/2in x 3ft 1/4in	1	$ 18.00	**$ 18.00**
Miscellaneous Components (extra wiring, extra fastners, etc.)				***23%***			***$ 656.32***
						Total Cost (w/o tax):	**$ 3,509.89**

Table 6.1 – Smart Mirror Total Bill of Materials.

VII. Conclusion

The paper demonstrates the development of functioning solutions for improvement of e-commerce field, in particular a clothing retail branch. The electrical and operational sides of the system have been tested, and as a result it was able to project AR-clothing models on the human body while basing the operation on the developed architecture. Even though some minor flaws in software operation were identified, the system performs up to expectations for the current stage of development.

7.1 Limitations

Project execution faces several limitations, that obstructed the ability of ideal product development and simulation:

- **Budget**

  The total cost of the project (without accounting for hours) exceeds the available funds, hence only partial build could be executed, and only electrical components were introduced in the system.

- **Web-Camera Technology**

  Ideally the system was planned to use a single 4K web-camera with the steady frame rate of 120 frames per second for the motion-tracking unit, to ensure smooth gesture recognition and

gradual frame update. However, no product that satisfy the criteria was identified on the market, and the next best solution was implemented – 1080p at 60fps.

- **Body Tracking and Projection Technology**

  Despite the fact that the fundamental operation is supported by the developed system, clothing projection technology requires major improvements from both sides: body tracking and clothes modeling, in order to give the user an experience of real try-on process.

7.2 Future Work

Future work on this thesis topic can be directed through two different paths:

1. Working on the current stage of the project, and improving the flaws of the built mentioned in the limitation section, in particular covering the software development.

2. Building on top of the existing system. Develop the solution that tracks the items in exiting wardrobe, provide the clothing to the user upon selection, and maintain storage conditions to eliminate fabric degradation.

VIII. Sources

7.1 References

1) *Acrylic Mirror vs. Glass Mirror*. Tree Towns Digital Decor. (2022, January 24). https://www.treetowns.com/acrylic-mirror-vs-glass-mirror/

2) *Acrylic mirror*. Emco Plastics. (n.d.). https://www.emcoplastics.com/acrylic-mirror/#:~:text=Acrylic%20Mirror%20is%20made%20from,by%20a%20durable%20protective%20coating.

3) *Aluminum sustainability. Infinitely Recyclable. Uniquely Sustainable.* The Aluminum Association. (2021). https://www.aluminum.org/sustainability

4) Basu, T. (2023, April 19). *Snap is launching augmented-reality mirrors in stores*. MIT Technology Review. https://www.technologyreview.com/2023/04/19/1071849/snap-ar-mirrors/

5) *Choosing glass or acrylic for your smart mirror*. Built by Az. (2018, October 2). https://builtbyaz.com/smart-mirror/glass-or-acrylic/

6) *First look smart mirror*. Mysize. (2023, January 3). https://mysizeid.com/first-look-smart-mirror/

7) Fox, S. (2023, June 6). *Online shopping statistics, facts & trends in 2023*. Cloudwards. https://www.cloudwards.net/online-shopping-statistics/

8) Hirschmiller, S. (2023, May 19). *Why the new generation of AR Smart Mirrors are catnip for fashion and beauty retail*. Forbes. https://www.forbes.com/sites/stephaniehirschmiller/2023/05/19/how-ar-mirrors-offer-visual-marketing-meets-user-generated-content-for-fashion-and-beauty-retail

9) INDE LLC. (2020, November 26). *Vyu: Virtual Fitting Mirror Launches*. INDEstry. https://www.indestry.com/news/inde-vyu-digital-fitting-mirror

10) *Metal weight calculator*. Steel Weight Calculator - Stainless, Aluminum, Nickel, Titanium & More! | TW Metals. (2019). https://www.twmetals.com/resources/calculators.html

11) Perez, S. (2023, April 19). *Snapchat's AR technology comes to the real world with "ar mirrors."* TechCrunch. https://techcrunch.com/2023/04/19/snapchats-ar-technology-comes-to-the-real-world-with-ar-mirrors

12) *Plexiglass vs Acrylic: What's the Difference?* Missouri Glass. (n.d.). https://www.missouriglass.com/blog/plexiglass-vs-acrylic-whats-the-difference/

13) Priest, D. (2020, January 8). *Smart mirrors just make you hate yourself*. CNET. https://www.cnet.com/home/smart-home/smart-mirrors-just-make-you-hate-yourself/

14) Prouty, C. (2019, January 8). *CES 2019 - LG thinq smart mirror*. YouTube. https://www.youtube.com/watch?v=ePFrRkW2jHI

15) Rinkesh. (2022, July 29). *Is MDF environmentally friendly and biodegradable?*. Conserve Energy Future. https://www.conserve-energy-future.com/is-mdf-environmentally-friendly.php

16) *Stainless Sustainability: The circular economy of Metal*. Ulbrich. (2020, October 3). https://www.ulbrich.com/blog/stainless-sustainability-the-circular-economy-of-metal/

17) Stanfield, S. (2021, November 30). *Is acrylic recyclable? 8 facts you should know (+3 alternatives)*. Citizen Sustainable. https://citizensustainable.com/acrylic-recyclable/#1_Polycarbonate

18) Suso. (2020, July 25). *Types of MDF boards for woodworking*. Paoson Wood Working. https://www.paoson.com/blog/en/types-of-mdf-boards-for-woodworking/

19) Sustainability Panel. (2019, June 1). *Considerations when choosing Sustainable Materials*. The Institution of Structural Engineers. https://www.istructe.org/resources/guidance/sustainability-considerations-choosing-materials/

20) Taylor, N. (2023, March 22). *Tommy Hilfiger uses AR Tech in three key stores for Shawn Mendes Launch*. Fashion Network. https://ww.fashionnetwork.com/news/Tommy-hilfiger-uses-ar-tech-in-three-key-stores-for-shawn-mendes-launch,1498758.html

21) *Virtual try-on for smart mirrors*. Reactive Reality. (2023, March 2). https://www.reactivereality.com/virtual-try-on/smart-mirror

22) VirtualOn Group. (2023, June 7). *Interactive fashion mirror: Virtual fitting or dressing room*. Virtual On. https://virtualongroup.com/interactive-fashion-mirror-virtual-fitting-dressing-room

23) Worst, R., Worst, J., & Miller, C. (2023, May 9). *5 mirror alternatives for when Glass just won't do*. Worst Room: Home Design. https://worstroom.com/mirror-alternatives/

24) *Zero10: AR-Fashion Platform*. Zero10. (2023). https://zero10.app/

7.2 Marketplaces

25) MetalDepot: https://www.metalsdepot.com/stainless-steel-products/stainless-steel-flat

26) MDF Direct: https://mdfdirect.co.uk/

27) PlasticStockList – Bay Plastic: https://www.plasticstockist.com/Default.aspx

28) Grainger: https://www.grainger.com/

29) McMaster-Carr: https://www.mcmaster.com/

30) NewEgg: https://www.newegg.com/

31) NewEgg Business: https://www.neweggbusiness.com/

32) BestBuy: https://www.bestbuy.com/

33) The Home Depot: https://www.homedepot.com/

34) Amazon Marketplace: https://www.amazon.com/

VII. Appendix

All supporting documentation is attached to the submission as **SM_Thesis_Documentation.zip** file for the reference of the committee. The list of attachments is presented below:

Excel Files

1. SM_Thesis_FS_General Tables [07.03.23]
    - 1.1 Competition Analysis Matrix
    - 1.2 Operational Modes Matrix
    - 1.3 System Icons
    - 1.4 Flow-Chart and Icons

2. SM_Thesis_FS_System Components [07.03.23]
    - 2.1 Electrical Bill of Materials (Extended)
    - 2.2 Electrical Bill of Materials (Compressed)
    - 2.3 Single-Line Icons
    - 2.4 Mechanical Bill of Materials (Extended)
    - 2.5 Sustainability Analysis
    - 2.6 Manufacturing Design Efficiency (Calculations)
    - 2.7 Manufacturing Design Efficiency (Compressed)
    - 2.8 Overall System Bill of Materials

2.9 Cameras Selection

PowerPoint Files

3. SM_Thesis_FS_1-Line E-Diagram [07.03.23]

3.1 Single-Line Diagram

3.2 Components IDs

4. SM_Thesis_FS_Visual Design [07.03.23]

4.1 Screen Samples

4.2 Widgets and Buttons

4.3 Operational Flow Chart

PDF Files

5. SM_Thesis_FS_Endorsment [07.05.23]

CAD Files

6. Thesis_FS_Smart_Mirror_Ass

6.1 SM_Thesis_FS_Comp.Mount_SubAss

6.2 Cmp_Mount_Plate

6.3 X399_w_IO

6.4 Nvidia GT-1030

6.5 Noctua-NH-L12S

6.6 Corsair Dominator Platinum DDR3

6.7 Power_Supply_Fixture

6.8 Corsair RM750

6.9 [8961K18]Steel_DIN3_Rail

6.10 [4418N11] DIN-Rail Mount Circuit Breaker

6.11 Power_Supply_Cord

6.12 [92095A127] M5x0.8x15_Button_Screw

6.13 [92000A215] M4x0.7x5mm_Phillips_Screw

6.14 [7578K22] Wire_Duct_4

6.15 [7578K22] Wire_Duct_5

6.16 [7578K22] Wire_Duct_7

6.17 SS_Frame_Vrt

6.18 SS_Frame_Hrz

6.19 Wood_Facia_TS

6.20 Wood_Facia_BS

6.21 Wood_Facia_LS

6.22 Wood_Facia_RS

6.23 Wood_Facia_Ext

6.24 Wood_Facia_Int

6.25 Reflective_Srfc

6.26 Samsung_UN65TU8000

6.27 HDMI_Cable

6.28 AverMedia_PW513

6.29 Noctua NF-A12x15

6.30 [19155K154] Fan Shielded Guard

6.31 [1088A41] 2in_Inside-Corner_Bracket

6.32 Type-B_Power_Cable

6.33 Screen_Power_Cable

6.34 Fans_Wiring

6.35 [7578K22] Wire_Duct

6.36 [7578K22] Wire_Duct_0

6.37 [7578K36] Wire_Duct_1

6.38 [7578K36] Wire_Duct_2

6.39 [7578K36] Wire_Duct_3

6.40 [90116A233] M4x0.7x40mm_Phillips_Screws

6.41 [90592A090] M4x0.7_Steeel_Nut

6.42 [53GJ20] M5x0.8x35mm_Button_Screws

6.43 [93625A350] M10x1.5_Steel Locknut

6.44 [92095A416] M10x1.5x30mm_Button_Screw

6.45 [93625A200] M5x0.8_Steel_Locknut

6.46 [97763A458] M5x0.8x20mm_Button_Screws