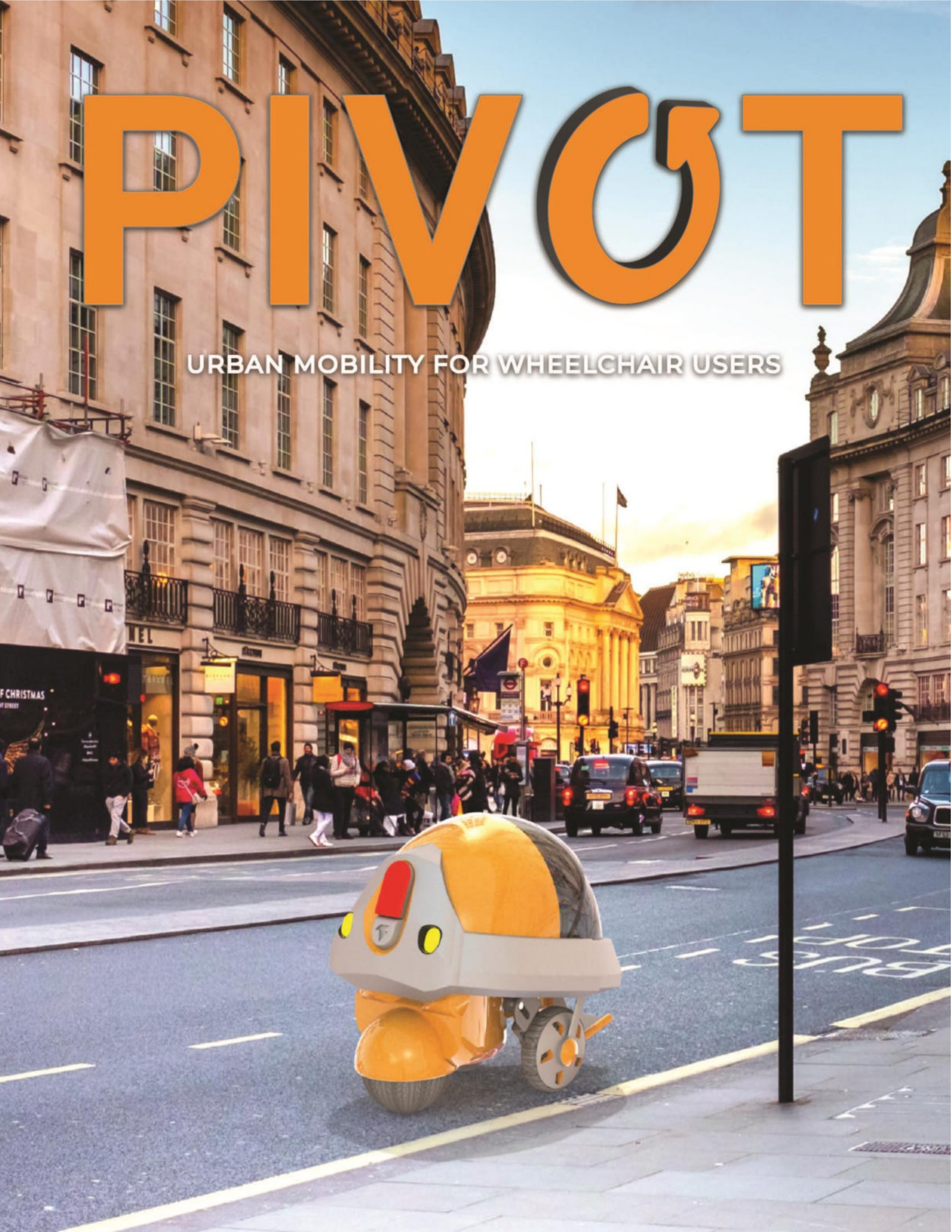
PIVOT

URBAN MOBILITY FOR WHEELCHAIR USERS



Urban Wheelchair Transportation for Wheelchair Users

by

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Faculty of Applied Sciences &Technology
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Abstract

As a civilization, we are continuously striving to be a more inclusive and accessible society. Since the invention of the automobile, we have been able to commute to work, the grocery store, or a friend’s house with ease. However, when envisioning vehicles for the future, little consideration has been given to the physically challenged community. Current solutions for accessible transportation have not evolved at the same rate as solutions for able-bodied users. Ramps can cause shoulder injuries, complex mechanisms require more than one user to operate, and some people are unable to manipulate controls such as a steering wheel.

The goal of this thesis is to improve transportation for wheelchair users in urban areas. Wheelchair users can feel isolated if they fear current transportation solutions cannot meet their needs. These people will search for living arrangements, jobs, and social circles that are immediately convenient instead of taking the risk of transporting through various environments. Environmental risks include congestion, physical terrain, and poor navigation. Using interviews and observational studies, these users’ pain points will be identified. A solution will be proposed that gives wheelchair users the freedom necessary to ensure equality. Additionally, a scale model of the solution will be created to showcase the design. By creating a new type of vehicle that allows independent, last-minute travel for wheelchair users, all members of society can have access to the benefits unlocked by the invention of the automobile.

Acknowledgments

I would first like to acknowledge my parents, Jim and Theresa, who have given me their unconditional love and support. They have been there for me through the highs and lows of the industrial design program, and the highs and lows of life itself. I am truly thankful.

I acknowledge the guidance given by my advisors and the Humber College faculty, namely Catherine Chong, Sandro Zaccolo, and Karen Medd, who have used their expertise to provide direction for this thesis. The Humber College industrial design faculty has helped me greatly in the process of becoming an industrial designer over the last four years, and Karen Medd is a wheelchair user who was kind enough to share her experiences in order to contribute to the justification of this thesis.

Last, I acknowledge my peers at Humber College. They have set a high standard in all areas of industrial design, and have pushed me to a higher personal standard as a result. The industry truly has a wealth of talent entering the workforce over the next few years.

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CHAPTER 1
Introduction

In this chapter, the topic of urban mobility for wheelchair users will be introduced and discussed. The issues with the current solutions will be briefly outlined, insights will be given, and societal impacts will be outlined. This chapter is intended to give context to the eventual solution that will be proposed in this thesis.

Figure 1

1.1 Problem Definition

Physically challenged individuals do not have the freedom of transportation offered to able-bodied users. Bicycles, streetcars, subway systems, and even sidewalks are all methods of navigating the city that the population may take for granted. When using a wheelchair, the options quickly begin to dwindle. While urban transit systems such as buses and subway cars are making changes to accommodate physically challenged individuals, the impact is still not enough. Many of the current accommodations for wheelchair users are retrofitted onto existing solutions which were not designed for wheelchair navigation. Some of the current solutions may be doing more harm than good. For example, when using a wheelchair ramp, an individual could have the pressure of 2-3 times their body weight on their shoulders (1). This could lead to injury, potentially disabling the user further. This thesis aims to provide easy, last-minute travel for all members of the urban community, including those with physical challenges.

1.2 Rationale & Significance

Figure 2

If a physically challenged person cannot trust the transit will successfully transport them, they could choose to stay home when others can move around freely. Subsequently, this could lead to feelings of isolation (1). This issue is further magnified by the amount of time management necessary for users to complete a trip. To use the TTC Wheeltrans vehicle which is specifically designed to accommodate a wheelchair, a customer must book a trip a minimum of four hours ahead of the desired pick-up or drop-off time (2). Lastly, these transit options such as buses and vans emit vast amounts of Co2. In the US, while only comprising about 5 percent of vehicles on the road, this class of vehicle generates more than 25 percent of emissions in the transportation sector (3).

To gain insights into the current market, and how the solutions offered can be improved, multiple research techniques will be used. First, the market landscape will be identified by accumulating vehicles from different classes. These vehicles will then be sorted based on the pro and cons of their designs. To find the pros and cons, a review of the literature and video materials will be conducted. These materials will be thoroughly analyzed using journey maps, empathy maps, and expert advice to identify pain points users face when using them.

1.3 Background, History, and Social Context

	% Total Population ≥15 y				Female (% WCS Users)	Mean Age (y)
	All WCS	MWC Users	PWC Users	Scooter Users		
Canada	288,800 (1.0%)	197,560 (0.7%)	42,360 (0.2%)	108,550 (0.4%)	175,210 (60.7%)	65.05
Province						
NL	4,830 (1.1%)	4,160 (1.0%)	780[b] (0.2%)	450[b] (0.1%)	3,120[b] (64.6%)	59.34
PE	1,160 (1.0%)	860 (0.7%)	210[b] (0.2%)	410[b] (0.4%)	580[b] (50.0%)	64.00
NS	10,150 (1.3%)	6,910 (0.9%)	1,470[b] (0.2%)	3,370[b] (0.4%)	5,630 (55.5%)	66.86
NB	7,780 (1.2%)	5,930 (0.9%)	1,350[b] (0.2%)	1,430[b] (0.2%)	4,360 (56.0%)	59.08
QC	54,410 (0.8%)	45,330 (0.7%)	6,940[b] (0.1%)	14,300[b] (0.2%)	34,240 (62.9%)	65.18
ON	121,170 (1.1%)	73,970 (0.7%)	16,320[b] (0.2%)	54,340 (0.5%)	77,960 (64.3%)	64.90
MB	13,500 (1.4%)	9,290 (1.0%)	1,930[b] (0.2%)	5,110[b] (0.5%)	7,890 (58.4%)	67.36
SK	10,080 (1.2%)	6,260 (0.8%)	1,350[b] (0.2%)	5,050 (0.6%)	5,790 (57.4%)	63.89
AB	18,920 (0.6%)	11,830 (0.4%)	3,950[b] (0.1%)	8,400 (0.3%)	10,990 (58.1%)	64.24
BC	46,320 (1.2%)	32,650 (0.9%)	8,010[b] (0.2%)	15,490[b] (0.4%)	24,390 (52.7%)	66.44
Territories	480 (0.6%)	370 (0.5%)	60[b] (0.1%)	130[b] (0.2%)	260 (54.2%)	64.55

Table 1: National and Provincial Prevalence, Sex, and Mean Age of WCS Users (All WCS and by Device Type Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4992144/

In 2012, The Canadian Survey on Disability released a report on Canadians 15 and over with physical limitations. They found there were approximately 289,000 Canadians who used a wheelchair or scooter (5). Compare this to the previous survey done in 2002, and the number is rising. This is mainly due to an aging population (5). According to Statistics Canada, the age of the population is projected to continue increasing, specifically in Toronto. The number of seniors aged 65 and over is projected to almost double from about 2.6 million, or 17.6 percent of the population in 2020, to almost 4.5 million, or 22.2 percent, by 2046 (4). Combine this with the fact that 1 in 4 Canadians are obese (6) and it is logical to expect an increase in demand for transportation options for physically challenged individuals who may use a wheelchair or mobility scooter.

While there have been some advancements in the area of wheelchair-accessible mobility, the current solutions still come across as too simplistic. When one simply adds a ramp into a vehicle, the ergonomic constraints of traditional ramps still apply. Other solutions such as lifts are incredibly cumbersome, expensive, and complicated. A vehicle large enough to fit a lifting mechanism must be large as well, thus requiring a large amount of expensive fuel to operate. Another setback with this type of vehicle is they often require a second person to act as a vehicle operator and assistant to the wheelchair user. This person may be a loved one or a paid assistant. There is still no viable solution for a wheelchair user who craves the freedom of last-minute, independent travel that the conventional automobile offers to able-bodied users.

CHAPTER 2: Research

2.1 User Research

This chapter will provide an analysis of user profiles and demographics, along with ergonomic comparisons, benchmarking, and a video study of current solutions. The insights will include identification of pain points, health, and safety analysis, and highlighting of current features included in existing products that are beneficial to the user. The deficiencies of these products will also be highlighted.

2.1.1 User Profile – Persona

The primary user for this thesis is reflected in the persona. The primary user is adults aged 18-65 who use a wheelchair to navigate work, stores, and transit systems. The secondary user for this thesis the elderly aged 65+ who have difficulty with mobility. Tertiary users are adults aged 18+ who use mobility scooters despite the ability to walk.

User: **Primary:** Physically disabled adults 18-65 **Secondary:** Elderly or retired 65+ **Tertiary:** Adults 18+ Who use mobility scooters despite the ability to walk	**Product (Benchmarking):** Wheelchair van conversions, TTC wheeltrans, Mobility converted vehicles etc.	**Environment of use:** Urban Commuting, Going to work, going out to socialize etc.
Primary- Young professional seeking job after graduation	TTC Wheeltrans	Going to job interviews
Secondary- Elderly person who lives with grown-up children	Rear-entry van	Going out to socialize, visit friends, play bingo etc.
Primary- Cerebral Palsy spokesperson	Wheelchair taxi	Going to schools to spread awareness
Primary- 18 Year old high school student	TTC wheeltrans	Going to and from school
Primary- Paralympian athlete	Side-entry van	Travelling to sporting events and training
Primary- Middle aged businessperson	Mobility adapted vehicle	Going to/from work and business meetings
Tertiary- Obese individual with difficulty walking	Side entry van	Going to grocery, clothing stores etc.
Primary- Paraplegic parent with 2 kids	Mobility adapted vehicle	Taking kids to school, soccer practice etc.
Secondary- Elderly person who lives in a long-term care home	Wheelchair taxi	Visit family for holidays and occasions
Primary- Young athlete with temporary injury	Wheelchair taxi	Going out to see friends

Table 2: Users, Products, and Environments of Use

Figure 3

Persona

Name: Shane

Age: 28 years old

Residence: Toronto, Ontario

Occupation: Web Designer

Income: $80,000 per year

Marital Status: Single

Wheelchair user: Yes

2.1.2 Current User Practice

Shane is an outgoing and vibrant young adult. He has a passion for computers and technology. He is the oldest of three children and serves as an example and mentor to his younger siblings. Due to his dedication to his career, Shane has recently moved out of his family home and into an apartment in the Greater Toronto Area.

Shane will regularly visit clients' offices while working as a freelance web designer. This means he must traverse unfamiliar environments regularly. He also values social time with friends, who enjoy playing video games or going out to the local bar with Shane. More mundane tasks for Shane include trips to the grocery store, drug store, and barbershop.

Irregular tasks for Shane include trips to the mall to update his wardrobe, GO-train journeys outside the city to visit extended family, and flights to the U.S to attend web design and UX conferences.

All of these tasks are heavily dependent on the wheelchair accessibility of the location Shane is going to. An area like the airport has staff dedicated to helping Shane get to his destination hassle-free. However, when Shane must visit clients to discuss a web design project, he needs to plan his journey well ahead of time if he has never been to that office before. Shane may have to plan this trip with a Wheeltrans service well ahead of time, then take his chance when navigating the area indoors.

2.1.3 User Observation – Activity Mapping

In this observation exercise, a typical task will be analyzed to understand the activities a user may go through. In this case, a video of a wheelchair user navigating Union Station in Toronto will be the source material. The goal of this exercise is to scrutinize the raw footage of the journey and recognize what is successful or unsuccessful.

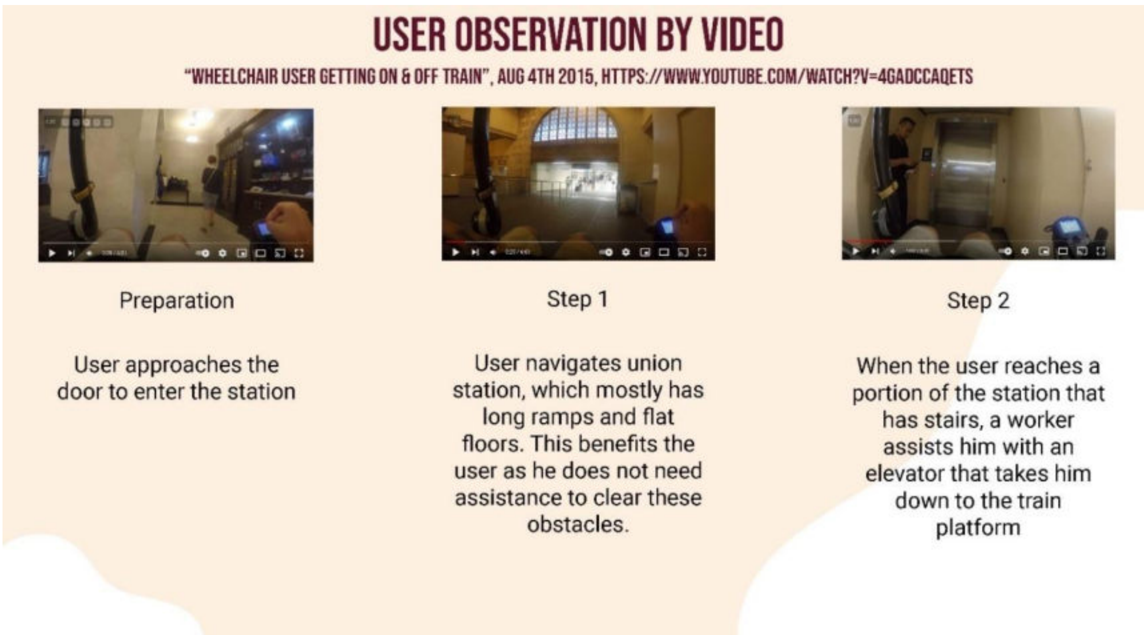


Figure 4

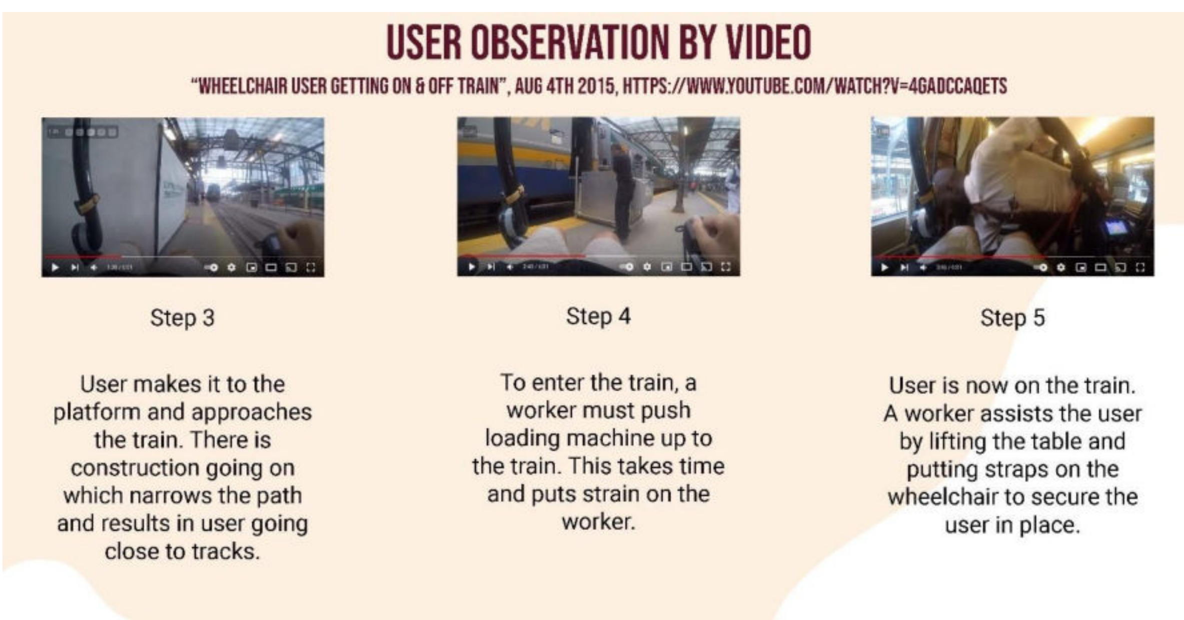


Figure 5

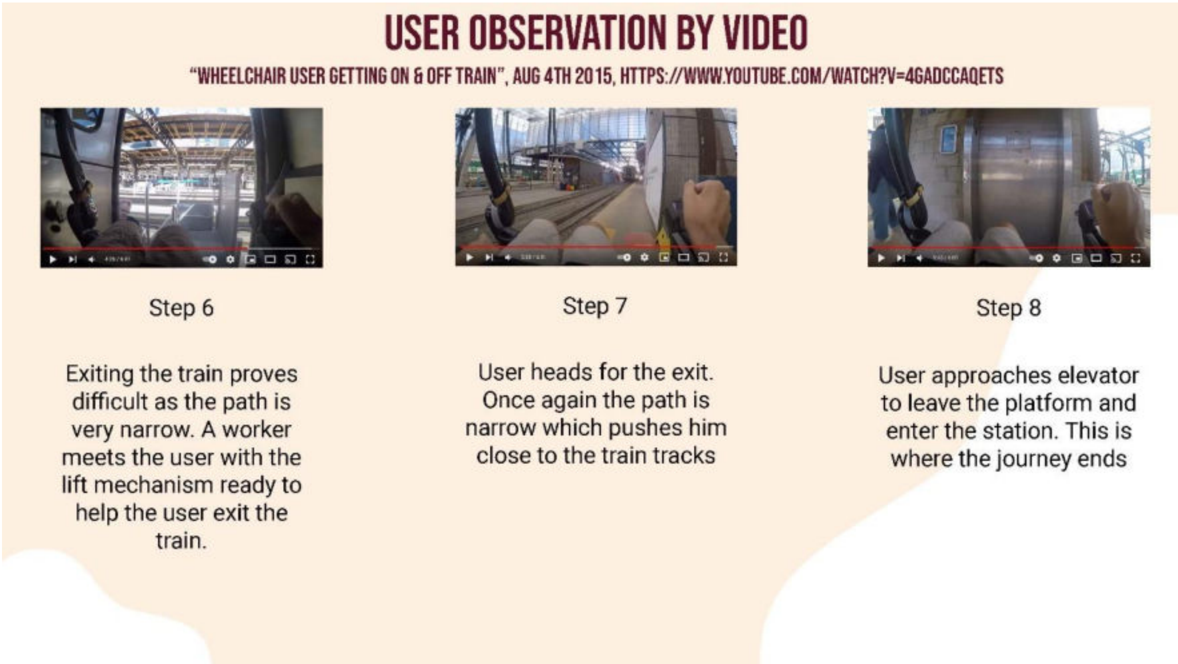


Figure 6

	Preparation	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8
User Goals	Enter station	Navigate ramps	Enter elevator	Navigate Platform	Enter train	Get secured for travel	Exit train	Navigate platform	Enter elevator
Actions	-Navigate around people - Open door - Go through door	- Approach ramp - Navigate around people - Go down ramp	- Worker presses button - Worker helps user enter - Worker rides with user	- Go around construction - Look out for people - Keep an eye on tracks	- Worker pushes lift up to train - User waits - Enter lift - Enter train	- User waits - Worker lifts table - Worker secures user to straps	- Navigate narrow isles - Enter the lift machine - Ride down off the train	- Go around construction - Look out for people - Keep an eye on tracks	- Worker presses button - Worker helps user enter - Worker rides with user
Thoughts	"Hopefully it's wide enough and not busy"	"I wonder if I'm blocking anyone"	"I wish I could do this without assistance"	"I need to go slowly to avoid the tracks"	"Good thing I'm not in a hurry"	"This worker is really in my personal space"	"This is really hard to get around the corner"	"Once again, I am close to the tracks"	"I'm glad that I made it safely"
Photos									
Experience									
Problems	Door is difficult to open	People are walking around	Takes a long time and is awkward	Construction pushes user near tracks	Takes a long time and is complicated	Worker has to invade personal space	Path is too narrow, is difficult to navigate	Path is too narrow, pushes user near tracks	Is time consuming

Table 3: User Observation Journey and Empathy Map

2.1.4 User Observation – Human Factors of Existing Products

When using a manual-powered wheelchair, even the top athletes can experience shoulder pain. Some sports that can be played in a wheelchair include basketball, tennis, and racing. The popularity of these sports is increasing, and the body of data is increasing as well. This data concludes that the shoulder is the most common site of complaint amongst athletes (7). Even during the day-to-day life of the common wheelchair user, going up a ramp can place 2-3 times the users' body weight onto their shoulders (8). If a wheelchair user injures their shoulders, this could impact their mobility even further. This human factor review will analyze a manual wheelchair that is designed specifically to be as ergonomic as possible.

Figure 7

The Karman S-305 includes many features that are specifically intended to improve ergonomics for the user. These include (9):

Adjustable seat width, either 16" or 18"
Seat height adjustment lever
Adjustable footrest
Adjustable headrest
Anti-tipping struts

A seatbelt
Extra upholstery if requested
Memory foam cushion
Contoured cushion
Suspension to improve ride smoothness

All of these features are designed with the user specifically in mind. An adjustable seat width allows a larger variety of percentiles to fit comfortably on the chair. Height adjustment allows the user to have a comfortable distance from the footrest, therefore reducing strain on the back, lower thighs, and hip bones (10). If the user sits too far above the wheels, they also will not be able to use their arms properly as they push. In general, the wheels should be grasped at the “ten-o’clock” position (11). By having adjustability, these wheelchairs can reach a larger demographic.

Safety features, such as the memory foam cushion and added upholstery, are features that are not necessarily related to ergonomics but make the user more comfortable when sitting for long periods. This is especially important considering that wheelchair users spend an average of 10.6 hours per day in their wheelchairs (12). Other non-ergonomic features that benefit the user include the seatbelt and anti-tipping struts. These safety features mean the user does not have to fear being in a dangerous situation when at home alone.

2.1.5 User Observation – Safety and Health of Existing Products

When the differently-abled are navigating urban areas, their health and safety are of the utmost importance. The health of the user can include their physical health, mental health, environmental health, and overall safety. Upon researching existing products, none truly cover every category listed above. Manual wheelchairs can strain the users' arms over time, and powered wheelchairs are often too cumbersome to navigate tight indoor areas. Vehicles such as scooters and wheelchair-accessible vans can pollute their environments and contribute to congestion in dense urban areas.

When discussing mental health, the issue is more complicated. While experiences can vary between users, people with disabilities experience frequent mental distress 5 times more than able-bodied individuals according to the CDC (13). One of the contributing factors to this distress is isolation (13) which has been listed as a symptom of wheelchair users in urban areas due to their lack of confidence in transit systems (1).

If an individual is unable to operate a conventional automobile, they have very limited options to travel outdoors in urban areas. While solutions such as the Kenguru wheelchair-accessible vehicle exist for these individuals, they are unrefined, expensive, and require a ramp to enter and exit (14) which is not ideal for wheelchair users as it could injure their shoulders (1).

2.2 Product research

The method used to research existing products is benchmarking of current solutions. This gives an idea of what products have been refined over the years, and what emerging technology may be refined in the future. Many features can be integrated into the eventual solution purposed in this thesis. These products range from wheelchairs to wheelchair-accessible vans because the proposed solution intends to use features from both forms of transportation. These products can be seen below.

2.2.1 Benchmarking – Benefits, and Features of Existing Products

Product Features/Comparison							
Product							
Dimensions LxWxH	38"x25.5"x37"	38"x26.5"x35.5"	42"x28"x40"	36.9"x18.1"x35"	90"x46"x63"	82"x29"x42"	203.7"x67.7"x69.9"
Weight Capacity	369lbs	450lbs	300lbs	300lbs	550lbs	600lbs	1000lbs ramp weight capacity
Range	24km	Arm powered	Arm powered	22km	56km	64km	250+km
Material	Aluminum Alloy	Steel	Carbon steel	na	Steel	Steel	Steel
Max Speed	6km/h	Arm powered	Arm powered	6km/h	29km/h	24km/h	150km/h +
Foldable	✓	✓	✓				
Weather Protection					✓		✓

Table **4**: Product Feature Comparison

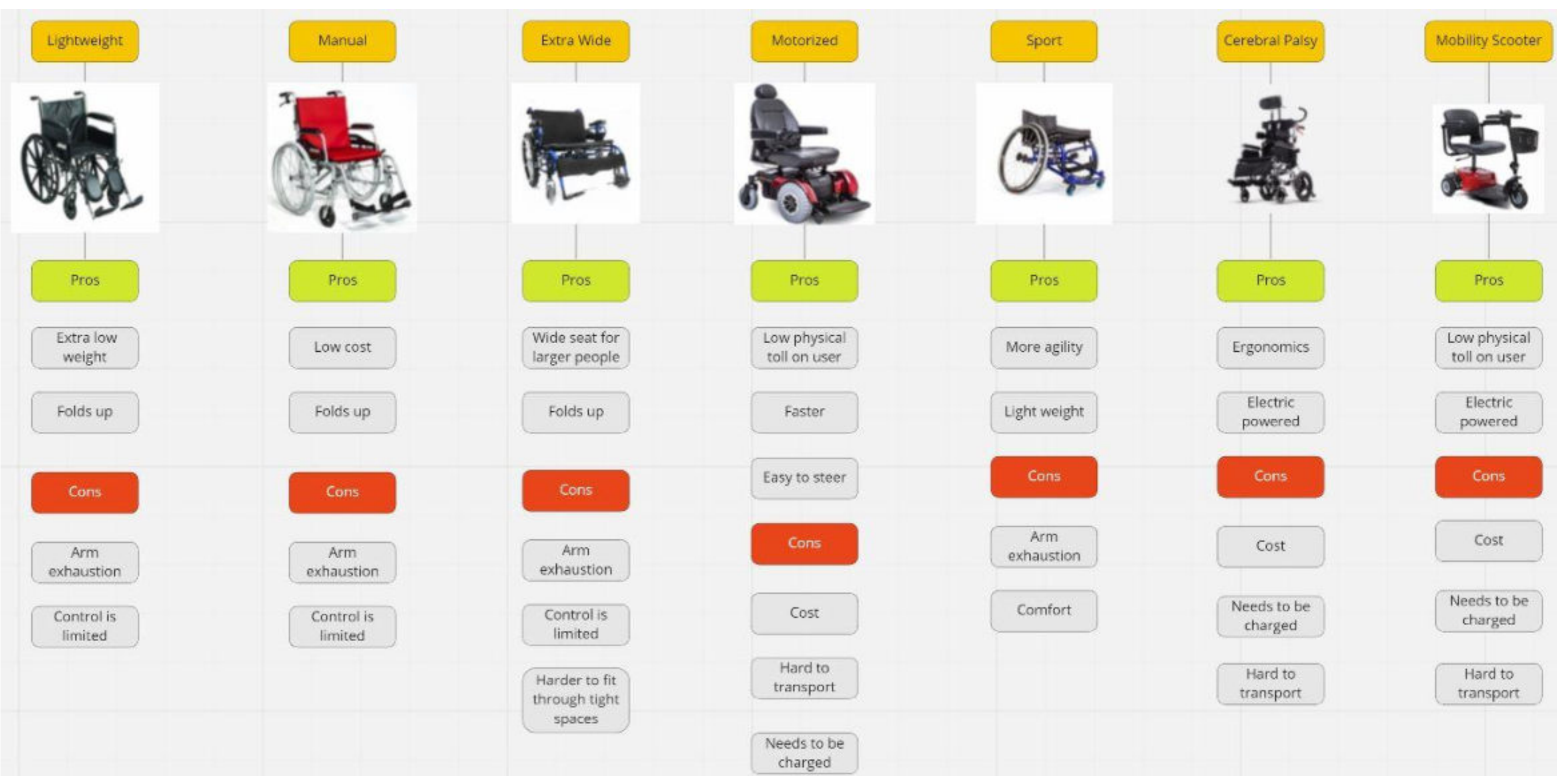


Figure 8

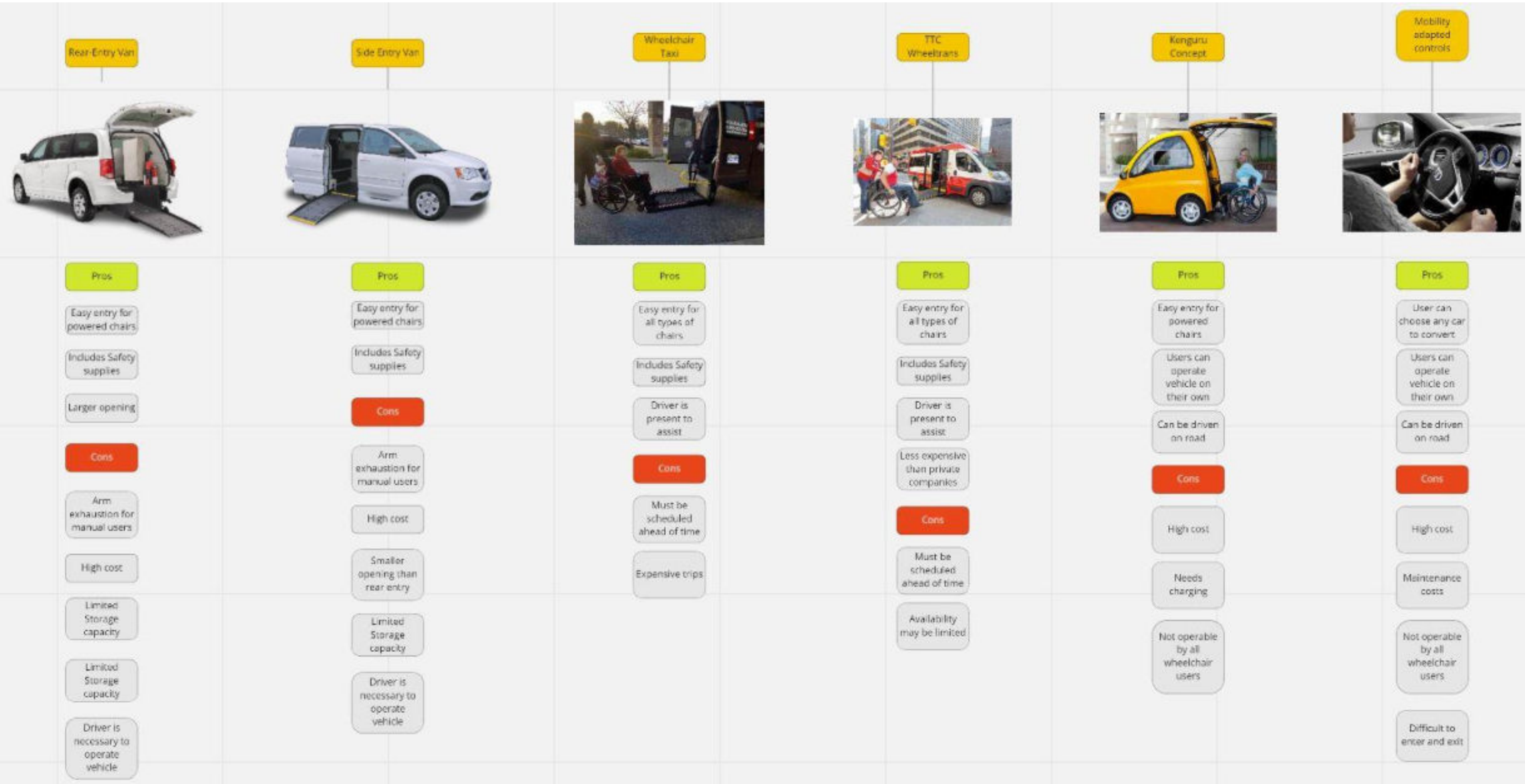


Figure 9

As seen in the figures above, there are a few takeaways from this benchmarking exercise. First, most manual wheelchairs weigh more than 300 pounds (table 4), thus making them too heavy to lift by most individuals, especially those using the wheelchair. This means that it is feasible to add safety features to the chair at the expense of added weight because they are difficult to lift regardless of features and power source.

In terms of wheelchair-accessible vans, all require a ramp or lift of some kind. This makes them difficult to maneuver in urban areas because the ramps extend well beyond the footprint of the vehicle to allow enough area to accommodate wheelchair entrance. The ramps are difficult for manual wheelchairs to maneuver (1), and the lifts are heavy, complicated, and expensive.

2.2.2 Benchmarking – Functionality of Existing Products

While there is a wealth of options for the urban wheelchair user, not many of them can truly solve all the pain points of the targeted primary user. Most of the wheelchair options seen in figure 8 allow for indoor maneuverability, especially in a space such as a shopping mall, but do not offer any kind of weather protection. The outdoor vehicles seen in figure 9 all offer weather protection and urban mobility, but the wheelchair itself is an after-thought.

Figure 8

Vehicles such as the Kenguru Concept seen above are a solution for urban wheelchair users who need to travel short distances. However, the access point in the rear features a ramp. As discussed in section 2.1.4, steep ramps are strenuous on the users' shoulders. The large hatch would also need significant clearance behind the vehicle which is not ideal for urban areas. Once the user exits the vehicle, they still use a conventional wheelchair to navigate the city which may have limitations as well, especially indoors.

2.2.3 Benchmarking – Aesthetics and Semantic Profile

Included in the benchmarking process are the aesthetics and semantics of the existing products. Wheelchairs usually are very functional above all. When dealing with physically challenged users, the controls have to be simple and obvious. Overly complicated controls can be overwhelming, confusing, or even dangerous when the user relies on this device to navigate around areas with inherent danger such as vehicles or other pedestrians. With all this in mind, there is a rationale for the somewhat mundane designs currently available. Vehicles such as the Kenguru in Figure 8 are starting to introduce more color and daring design flair. This is the direction that most products are headed in the future as each product attempts to stand out from the crowd.

2.2.4 Benchmarking – Materials and Manufacturing

Powered vehicles often utilize materials that offer the appropriate blend of lightness and strength. However, the more complicated the vehicle, the more complex and heavy-weight it will become. When one is choosing materials for an urban commuter vehicle, one must consider strength, weight, and cost. A vehicle such as a high-end bicycle made for urban commuting will feature materials such as 6061 aluminum for the frame to ensure lightness, 13 gauge stainless steel in the spokes to ensure strength and durability, and lithium-ion batteries to provide a compact power source. However, using these materials give the bike a higher cost when compared to a more basic steel frame bike (13).

When creating an environmentally friendly, fully electric passenger vehicle with crash protection the size, weight, and complexity of materials must increase. For example, the Renault Twizy is described as “somewhere between a moped and a car” (14) and is designed to be an urban mobility solution with crash protection and electric power. To be as innovative and environmentally friendly as possible, Twizy used some ground-breaking materials and manufacturing processes. To create the body panels, a process known as UV-curing pultrusion allows the forming of reinforced composites that result in lightweight and high-strength body panels. The process can be seen in *figure 13*.

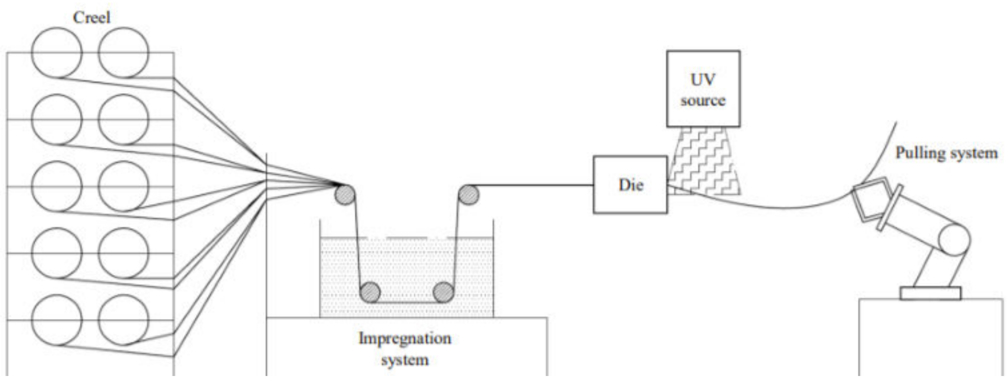


Figure 13

When looking at the future of plastic materials, another intriguing emerging technology is starch-based polymers. PLA, which is made from sugars, is already used as a substitute for petroleum-based plastics in applications such as packaging, 3D printing, and automotive insulation. PLA can be made to look behave very similarly to other plastics such as polypropylene which is currently used in the automotive industry (15).

The proposed design solution looks to implement a blend of the materials above to maintain the characteristics of an urban commuter vehicle for wheelchair users. The exterior panels of the vehicle aim to use reinforced composite materials to maintain a lightweight, low cost, and high-crash safety from the rear, and rear ¾ angles.

The chassis of the vehicle will feature the use of lithium-ion batteries, a drivetrain, and a charging plug similar to an electric car as seen below in *figure 14*. However, the front two wheels of the proposed solution will have an independent battery, plug, and drivetrain than the rear wheels for the wheelchair portion to decouple and operate independently. For structural components of the chassis, aluminum will be used to keep the vehicle lightweight.

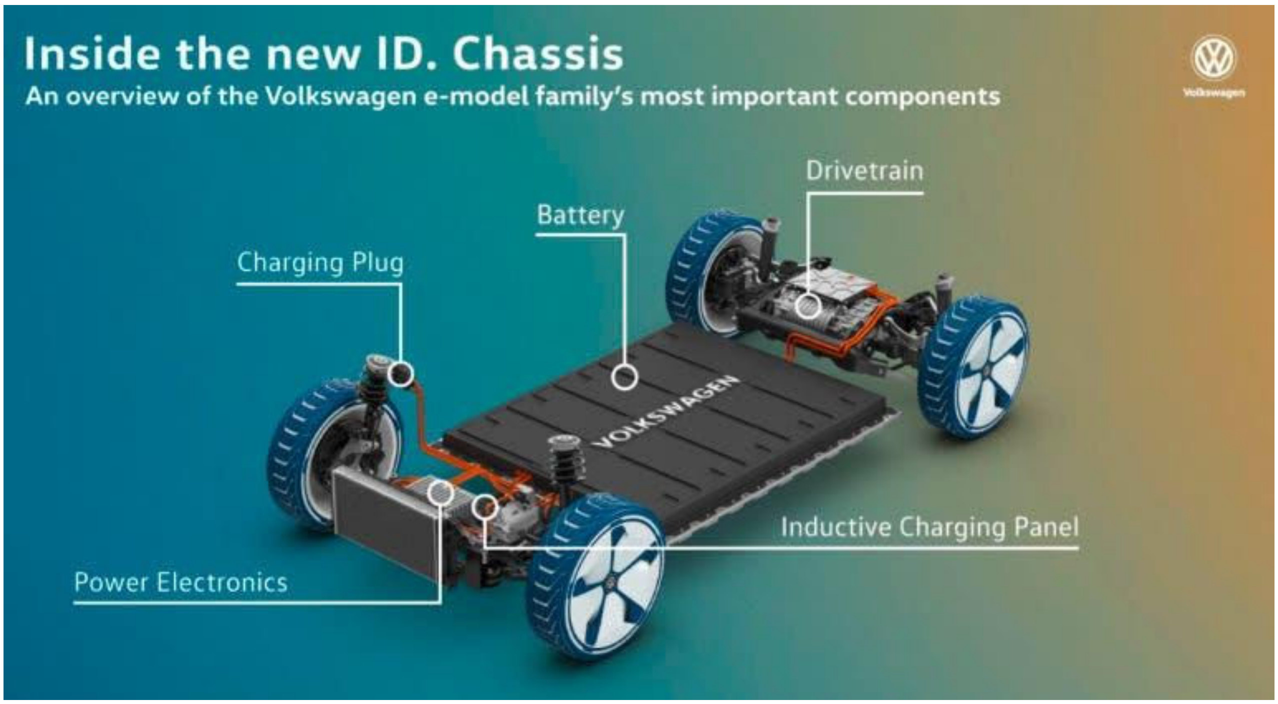


Figure 14

Other components of the vehicle's frame will use a mix of steel and aluminum depending on the strength necessary for collision protection. For example, the spokes of the wheels will use steel to be extremely durable over a long period. Aluminum wheels may exist; however, they can be prone to denting which would be extremely inconvenient for a wheelchair user. Steel wheels are also easier to repair and cost less (16). This level of strength will not be necessary for the frame, as manufacturers such as Ford and Audi have been using aluminum for their frames in recent years as seen in an example of an Audi shown in *figure 15.* A similar type of frame would provide an ideal base for the composite body panels to be attached to in the proposed design solution.

The proposed solution featured a large windscreen to provide weather protection for the operator of the vehicle. However, glass is too heavy, fragile, and expensive to shape into the moving panels necessary to retract as required. Polypropylene would be usable in the application needed; however, this type of plastic is petroleum-based. Therefore, PLA biodegradable plastic as mentioned above will be used for the windscreen to be in keeping with the theme of environmental consciousness. Other applications of this plastic can be applied to components such as the front a rear light housing, side reflectors, and vehicle control buttons.

Figure 15

2.2.5 Benchmarking – Sustainability

Material	Properties	Reference
6061 Aluminum	"Alloy 6061 It has a relatively high strength, easily welded and is widely used not only for making bicycle frames, but also in construction, aircraft, shipbuilding. Like all 6xxx series alloys Alloy 6061 It is thermally hardenable alloy. Heat treatment, which is applied to the already welded frames, is heating up 530 ° C, intensive cooling with water, and artificial aging at a temperature of about 180 ° C. 8 hours. Aluminum alloy 6061 after such treatment designate 6061-T6."	https://aluminium-guide.com/en/velosipednaya-rama-alyuminievye-splavy-6061-i-7005/
13 Gauge Steel	"Durability is a major advantage when it comes to steel wheels. Cracking a steel wheel is nearly impossible and bending a steel wheel would require tremendous force. As long as you maintain the layer of paint on your wheel as needed, your steel wheels will not rust."	https://www.blackburnwheels.com/alloy-wheels-vs-steel-wheels-pros-cons-guide/
Lithium-Ion Batteries	"They have one of the highest energy densities of any battery technology today (100-265 Wh/kg or 250-670 Wh/L). In addition, Li-ion battery cells can deliver up to 3.6 Volts, 3 times higher than technologies such as Ni-Cd or Ni-MH. This means that they can deliver large amounts of current for high-power applications, which has Li-ion batteries are also comparatively low maintenance, and do not require scheduled cycling to maintain their battery life."	https://www.cei.washington.edu/education/science-of-solar/battery-technology/
Reinforced Composite	"Glass fibre reinforced polymer composites, GFRP, have gained substantial interest over the last years, mainly due to their high specific stiffness and strength, high impact energy absorption per unit of weight, noise suppression capabilities and excellent resistance to fatigue."	https://ec.europa.eu/research
PLA Polypropylene	"PLA (polyactic acid) is typically made from the sugars in corn starch, cassava or sugarcane. It is biodegradable, carbon-neutral and edible…PLA can look and behave like polyethylene (used in plastic films, packing and bottles), polystyrene (Styrofoam and plastic cutlery) or polypropylene"	https://phys.org/news/2017-12-truth-bioplastics.html
5182 Aluminum	"5xxx series is one of the most popular for aluminum car bodies. Its main alloying element is magnesium, known to increase strength…5182 shows up as a structural mainstay for car bodies. Everything from structural bracketry, to doors, hoods, and front wing endplates"	https://www.kloecknermetals.com/blog/aluminum-in-cars.

2.3 Summary of Chapter 2

The goal is to determine which features in existing products are relevant to the thesis and may help provide the ideal experience for a wheelchair user in an urban environment. The functionality is the priority when dealing with wheelchairs and other vehicles for the physically challenged, but the aesthetics need to be considered as well. To provide context, the primary, secondary, and tertiary users were identified and a persona was created. This persona will be kept in mind while making decisions on design, ergonomics, and features.

To better relate to this persona, user observation exercises were conducted and studied to highlight pain points of various wheelchair-specific situations. These situations were broken down scene by scene, and I noticed issues such as long wait times for ramps to be set up, and constant employee assistance required in various situations. This means the environments were not truly designed with the user in mind.

After looking at the situational issues, specific products were then researched and compared to get a sense of the current market landscape. Products such as wheelchairs, scooters, and vans were benchmarked because the proposed solution looks to incorporate the benefits of all mentioned vehicles. This exercise led to the realization that all wheelchairs are very heavy, so it may be worthwhile to add safety features at the expense of weight because users cannot possibly lift the wheelchair regardless of the included features and power source. Other takeaways included the fact that wheelchair vans require a tremendous amount of space to operate because ramps and lifts must extend beyond the footprint of the vehicle to accommodate wheelchair users.

Last, the materials and manufacturing of existing products were benchmarked to gain exposure to cutting-edge technologies that can help ensure modernity in the construction and technology of the proposed solution. Ideal solutions include an aluminum frame, reinforced composite body panels, and starch-based plastic components instead of the petroleum-based equivalent.

CHAPTER 3: Analysis

This chapter will prioritize the needs of the users, and uncover insights on how to meet these needs. Tools such as user observation, activity mapping, and ergonomic testing will be used to evaluate and organize areas of need. Health, safety, and manufacturing will be explored as well. The goal is to better understand how a wheelchair user moves through urban areas, and what designs would help them navigate more easily.

3.1 Analysis – Needs

Current solutions for wheelchair users in urban areas only take into account half of the journey. Wheelchairs, whether manual or powered, offer little to no weather protection or safety features when used outdoors. If the weather is cold or raining, how exactly is a wheelchair user supposed to navigate the area outdoors? The answer to this question is large vehicles that are entered by a ramp or lift. These vehicles are slow, emit Co2, and require a driver who must be paid and booked well ahead of time. A solution that takes into account the entire journey, start to finish, is currently not available on the market.

3.1.1 Needs/Benefits Not Met by Current Products

Wheelchair Taxi		Vehicle emits Co2	Mechanism is heavy and complicated	Needs room to load/unload	Requires human assistant	Van takes up large amount of space	Outdoor only
Motorized Chair		No weather protection	Battery has limited range	Large and heavy	Low top speed when outdoors	Difficult to maneuver in tight spaces indoors	Design is not modern or stylish
Scooter		Little thought put into ergonomics	No weather protection	Battery has limited range	Large and heavy	Difficult to maneuver in tight spaces indoors	Design is not modern or stylish
Wheelchair Accessible Urban Vehicle		Ramp is not ideal	Door mechanism requires large footprint	Handle-bar controls may not be accessible for all	Outdoor only	Only fits manual wheelchairs	Minimal Storage space

Table 6: Needs not met by current products

As seen above in Table 6, the current solutions have multiple limitations on what they provide to the user. Wheelchair taxis are large, gas-powered, and require large amounts of planning. Motorized chairs and scooters solve the issues of arm strength and exhaustion associated with wheelchairs, but do not offer weather protection or long-range. An example of a wheelchair-accessible urban vehicle solution is still lackluster due to its use of a ramp to enter and exit, as well as its large footprint when operating the door.

3.1.2 Latent Needs

Maslow's Hierarchy of Needs is the tool being used to evaluate the fundamental human needs of the user. Identifying these needs is intended to improve the quality of life for the user.

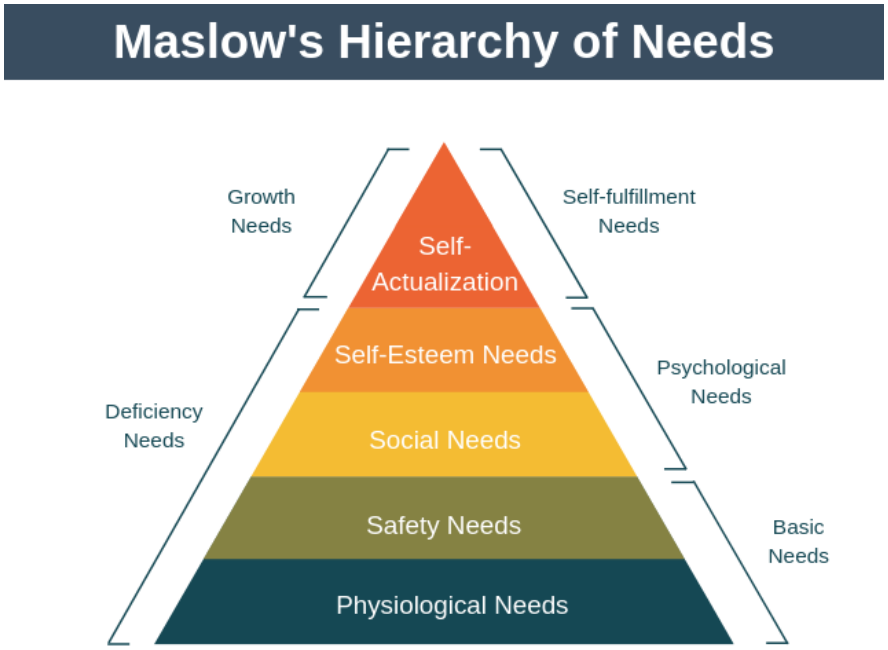


Figure 9

Benefit	Related Human Needs	Relation to Benefit
Ease of use	Safety Needs, Self-Esteem Needs	Moderate
Ergonomics	Physiological Needs, Safety Needs	Strong
Style	Self-Esteem Needs, Self-Actualization	Moderate
Comfort	Physiological Needs, Safety Needs	Strong
Freedom of travel	Self-Actualization, Self-Esteem Needs	Strong

Table 6: Latent Needs and Benefits

3.1.3 Categorization of Needs

This process will emphasize the users' needs based on Maslow's Hierarchy of Needs (Figure 9) more than specific product features, which were discussed in chapter 2. This information has been accumulated through literature review, user observation, journey mapping, and empathy mapping.

Wishes/Wants

Weather protection
Maneuverability
Comfort

Immediate Needs

To navigate urban areas
Safety for user
Controls that mitigate injury

Latent Needs

Style and dignity
To travel and explore
Be included in social circles

3.2 Analysis – Usability

To observe the usability of a solution for wheelchair travel, a video review was conducted. The materials for this review were found online. Each stage of the video has been identified and commented on to analyze the details of the product.

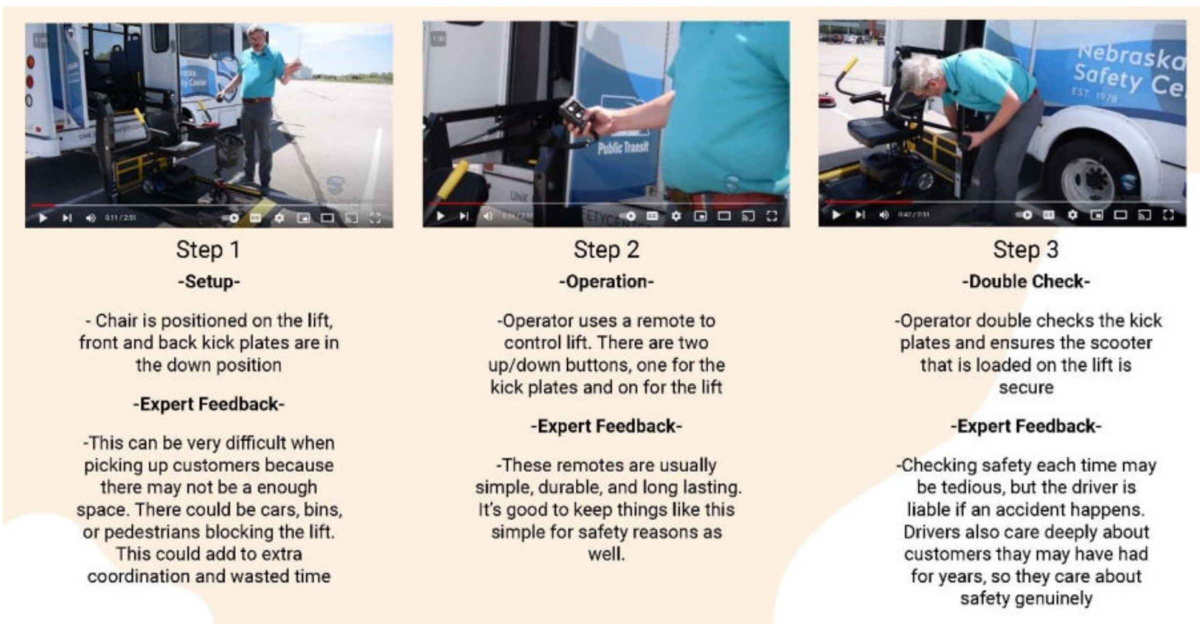


Figure 10

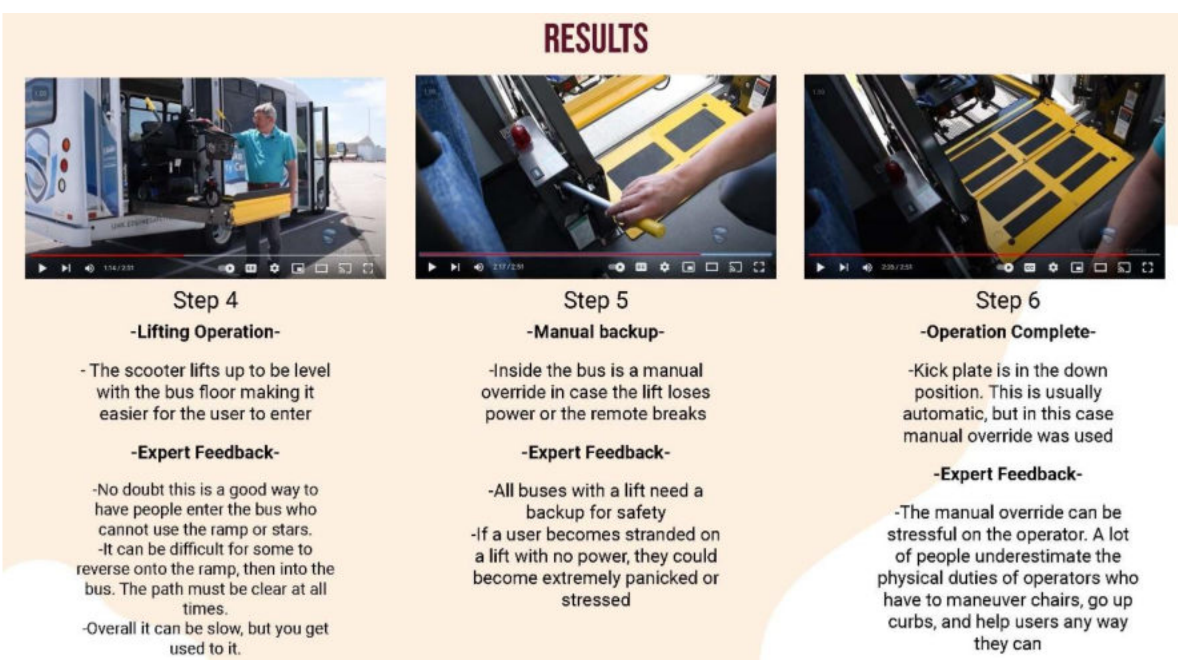


Figure 11

3.2.1 Journey Mapping

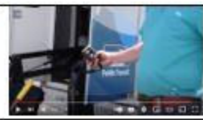
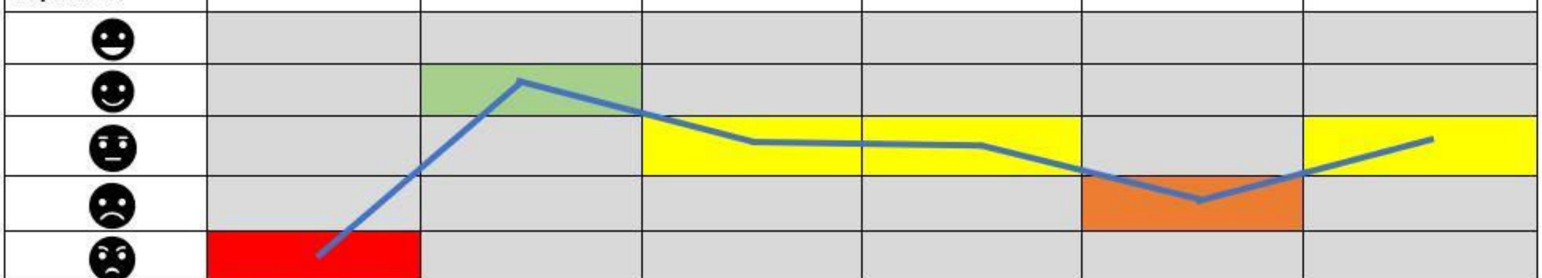
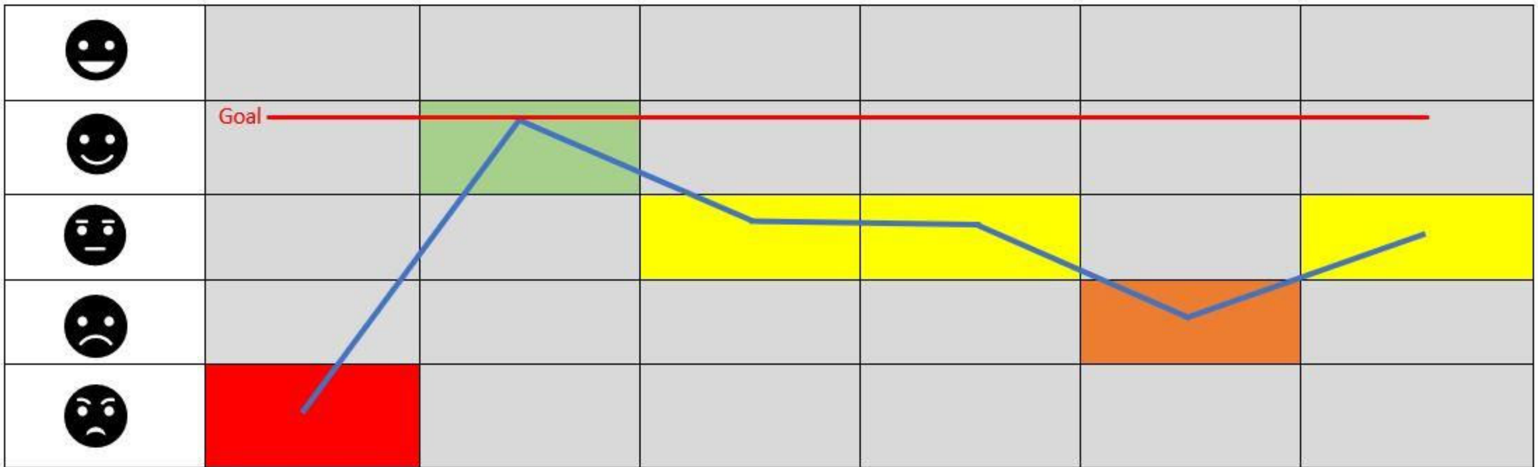
	Setup	Operation	Double Check	Lifting Operation	Manual Backup	Operation Complete
User Goals	Position chair on lift	Begin lifting	Check safety	Level platform to bus floor	Over ride battery operations	Watch user enter bus
Actions	- Ensure kick plates are down - Position bus in safe area - Supervise user to ensure safety	- Press buttons on remote - Lift chair slightly off the ground - Ensure user is comfortable	- Check front kick plate - Check rear kick plate - Ensure everything is secure on platform	- Wait for lift to rise up - Be patient as operation is slow - Once lift is complete, lower rear kick plate with remote	- Find manual override bar on the inside of the bus - Insert bar into slot - Begin pumping motion with bar until kick plates are down	- Double check kick plates - Watch user reverse into bus - Potentially aid user if they have any difficulties
Thoughts	- "I need to find a safe area to park" - "Hopefully the customer gave me good directions"	- "Are these buttons clearly labelled?" - "Hopefully the batteries are working"	- "Is the lift off the ground?" - "Are these kick plates secured?"	- "Is the customer getting impatient?" - "I hope they feel safe"	- "Hopefully the customer isn't panicking" - "Is this pumping motion going to injure myself?"	- "Are the kick plates down?" - "Does the customer need my help at all?"
Photos						
Experience						
Problems	-High stress environment for the operator -If there is no room, the driver may not pick up the user	-Remote may fail if batteries die	-Tedious and repetitive -Requires operator to bend over	- Operation is slow - Driver has nothing to do except wait	- The bar could easily be misplaced as it is loose - Operator has to pump lift up manually	- Operator may have to help user maneuver chair around

Table 7: Journey Mapping

The usability of this wheelchair lift highlighted a major flaw with this type of system. That flaw is the extremely large footprint necessary to park the vehicle, lower the lift, and raise the user to floor level. This flaw gives anxiety to both the driver and the wheelchair user being picked up or dropped off. Benefits of this current lift system are clearly labeled buttons, safety features such as kick-plates, and manual back-ups to electric-powered features.

3.2.2 User Experience



	Setup	Operation	Double Check	Lifting Operation	Manual Backup	Operation Complete
User Goals	Position chair on lift	Begin lifting	Check safety	Level platform to bus floor	Over ride battery operations	Watch user enter bus
Problems and Challenges	-High stress environment for the operator	-Remote may fail if batteries die	-Tedious and repetitive	- Operation is slow	- The bar could easily be misplaced as it is loose	- Operator may have to help user maneuver chair around
	-If there is no room, the driver may not pick up the user		-Requires operator to bend over	- Driver has nothing to do except wait	- Operator has to pump lift up manually	
Ideas and Takeaways	More compact and efficient lift that takes up less space	Solar power or a secondary power source	Automated safety checks, lights that turn from red to green	Reduce ride height of vehicle in order to reduce waiting time	A more ergonomic method of backup power such as crank or foot operation	Turnstile to have chair rotate automatically

Table 8: User Experience Map

The most stressful part of the sequence above is clearly the setup. This is because it is a high-stress environment when you factor in surrounding vehicles and civilians adding pressure. After all, the ramp takes up a large amount of space on the road or sidewalk. If the driver deems the situation unsafe, the user may not be picked up at all.

Overall, the steps required to operate the lift system are long, repetitive, and tedious. This is a solution that is not overly enjoyable for the driver or the wheelchair user. Time, energy, and patience are wasted by all users of this lift system.

3.3 Human Factors

The purpose of an ergonomic analysis is to determine the accuracy of the assumed dimensions related to a new product design. When creating a new form, the impact on ergonomics may not be apparent until the human body interacts with it on a 1:1 scale. In this analysis, the major touchpoints of a chair have been replicated to gain insights into the design and how it functions. Also included in the analysis will be dimensioned in relation to different body types, as well as a breakdown of the information presented. The section will end with a reflection on the study and a conclusion.

Literature Review

The ergonomic dimensions referenced in this analysis are from the Kate Gleason College of Engineering in Rochester, NY. This College has completed in-depth studies into wheelchair design and ergonomics as shown in *figure 13.* Examples of dimensions referenced include human body dimensions, overall wheelchair length, and angles of reach. Additional sources will be cited when used.

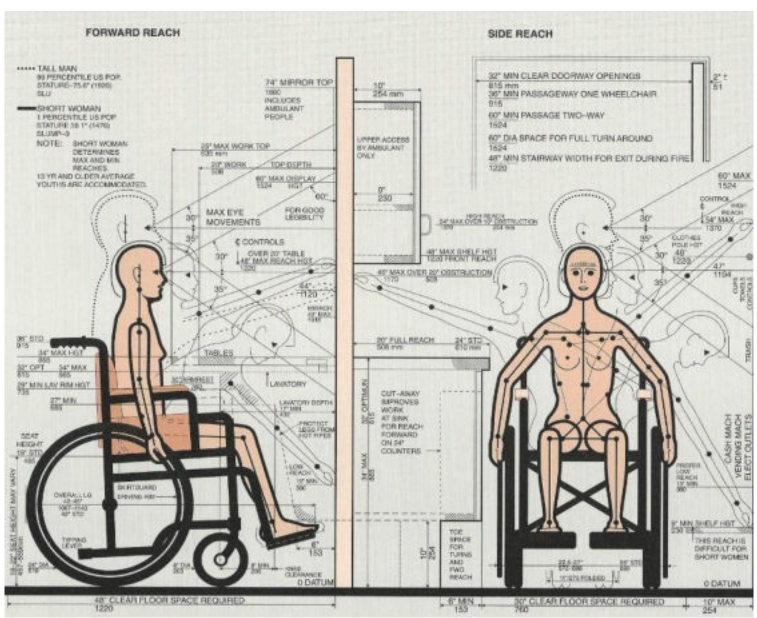


Figure 13

3.3.1 Product Semantic – Configuration Diagram

When creating dimensions and configurations, the wheelchair portion of the proposed solution was focused on. This was because this portion of the design is the only part that is interacted with by the user. The dimensions and configuration can be seen below.

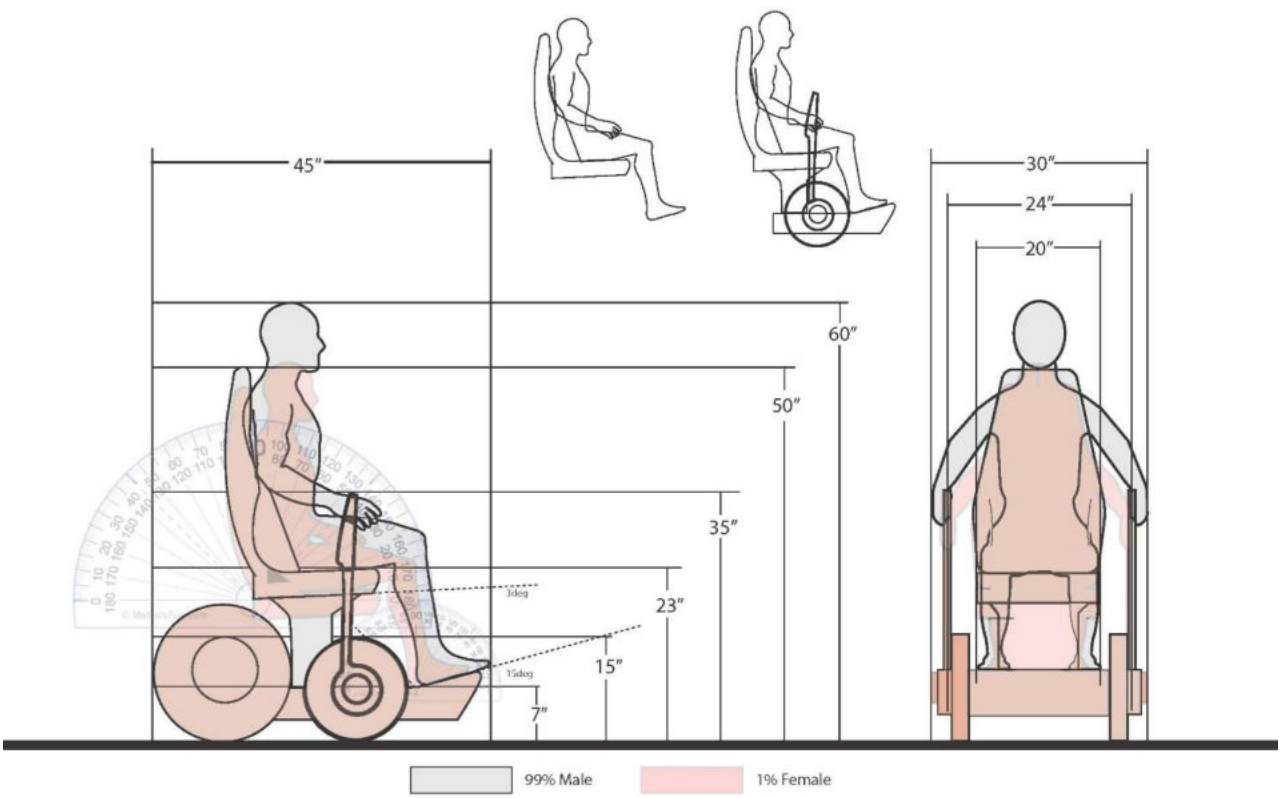


Figure 14

3.3.2

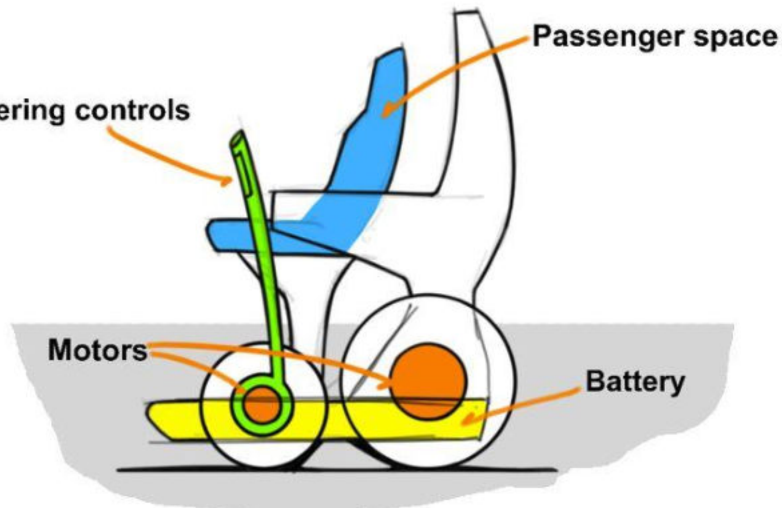


Figure 15

Ergonomic – 1:1 Human Scale Study

Methodology

The methodology for this ergonomic analysis began by creating sketches of a wheelchair. These sketches are design sketches, and therefore did not have dimensions included. The points of interaction in the design sketches were then recreated using accurate dimensions and inexpensive materials to provide a scenario in which real-life human interaction could occur. This recreation was constructed using pink insulation foam, cardboard, and hot glue along with an existing piece of furniture. See *figure 2*. These materials were chosen because they are easy to cut to shape, glued together, and stacked to create volume.

Figure 16

As seen in *figure 16, the* pink foam was used to replicate the appropriate seat height, depth, width, and angle. Cardboard was used to replicate seat back height, width, and angle as well as the footrest and hand controls at the appropriate heights, widths, and angles.

Results

With the 1:1 scale recreation completed; a human reference was asked to sit on the model as if it were a wheelchair that they would use themselves. This was to evaluate the interaction points of the product. The human referenced is a 53rd percentile male. Since the product is intended to be used as a wheelchair, the reference was asked to sit in a neutral position with their back firmly pushed into the seatback, feet on the angled footrest, and arms grasping the controls. This configuration is shown in *figure 17, figure 18, and figure 19.*

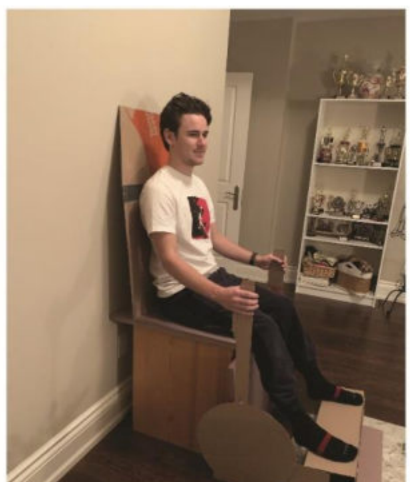


Figure 17

Figure 18

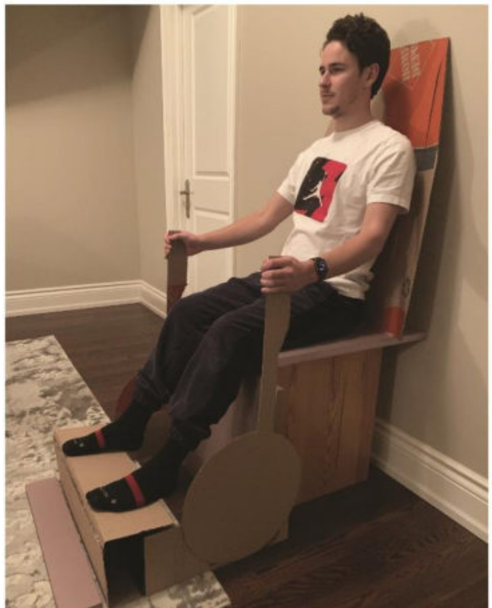


Figure 19

Analysis

After analyzing the results of the human-referenced ergonomic study, three key points of interaction were observed. The first point of interaction is the lower back. The angle of the seat bottom and seat back both affect the lower back ergonomics of the chair. The seat to floor height must be higher in the front and lower in the back to create pelvic stability and improve upper extremity function for wheelchair users (2). The second point of interaction is the feet on the footrest. The angle of the users' legs and feet should be less than 90 degrees when on the footrest to reduce strain on the back, thighs, and hips (3). This was accomplished by pushing the footrest away from the base of the chair. The third point of interaction is the controls, which are shown as two vertical extremities protruding from both sides of the chair. With this style of control, it is ideal for the user to have 100-120 degrees of elbow flexion when they initiate a pushing motion (4). As seen in *figure 6*, all these considerations have been taken into account.

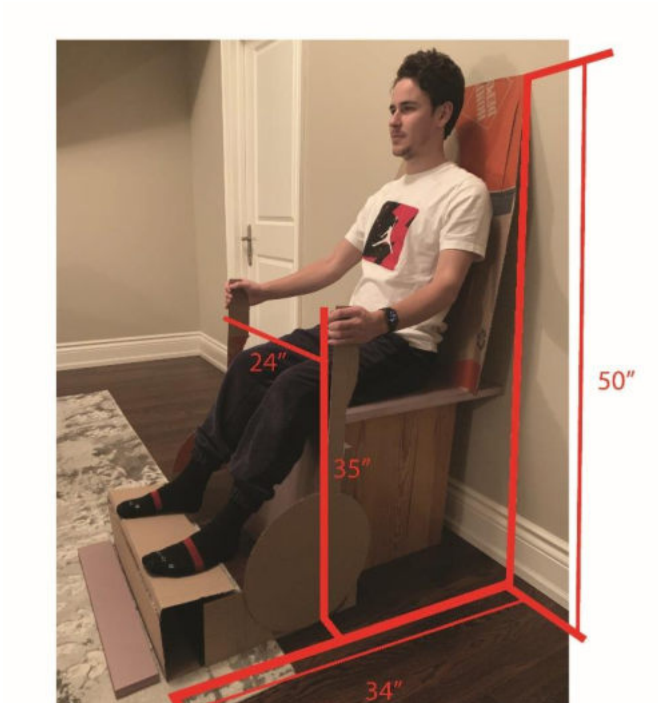


Figure 20

Limitations and Conclusion

An analysis has been conducted to gain insights into the ergonomics, touchpoints, and user interaction of a product design. These learning outcomes will be applied to future iterations of this wheelchair design. By constructing a 1:1 scale ergonomic model, and having a human reference interact with it, valuable insights have been collected. The three main interaction points where insights were collected are the lower back, feet, and hands. These are the main areas of focus not only for this design but for wheelchairs in general.

Limitations were observed in the same three areas. First, the seat angle was not steep enough. The purpose of the seat angle is to push the users' buttocks to the back of the seat to strengthen their seating position. Upon observation and user feedback from the human reference, the seat did not deliver this sensation. More consideration will be given to the seat angle in future iterations.

Second, the footrest was positioned too far away from the base of the chair. This position may be suitable for the 99th percentile user, but the 53rd percentile human reference found their legs were too far under 90 degrees, thus adding additional stress to the thighs. To resolve this issue, an adjustable footrest may be considered.

Last, the wheelchair controls positioned on the sides were observed to be too wide apart. When a user is sitting on the seat bottom and backrest, their arm angle should not be uncomfortable when operating the controls. While the vertical angle of the arms is an appropriate 100-120 degrees, the horizontal angle is too great. The controls will either have to be moved physically closer or be designed in such a way that they are angled more towards the user. Further development of the design will take place to take these observations into account, therefore improving the ergonomics of the design.

3.4 Aesthetics and Semantic Profile

The benchmarking techniques used in chapter 2 have helped focus on what is important when designing a product for this industry. One of the important elements in any design is aesthetics. When dealing with physically challenged users, the aesthetics need to communicate the function of the vehicle. There needs to be a certain level of honesty and clarity. This means that fake vents, doors, or engine covers are unacceptable.

This is not to say that a splash of color and design flair cannot be incorporated into the design. The current landscape of products is too mundane and has little thought put into the aesthetics. When designing for the persona of an urban adult aged 18-65, looking cool is a latent need that must be considered. The perfect balance would include clear intent and high levels of practicality that are designed with flair and out-of-the-box thinking. The design solution will aim to be honest and straightforward with its design lines, but still, have a look that young users will enjoy being seen in.

3.5 Sustainability – Safety, Health, and Environment

The purpose of designing a vehicle for urban wheelchair users is to ensure that users can navigate dense, populated areas, both indoors and outdoors. To achieve this outcome, the wheelchair must become smaller and more maneuverable. The wheelchair must also be able to travel short distances outdoors and offer some protection to the user when navigating around vehicles such as cars and bikes.

Safety

When designing for the differently-abled community, safety is of the utmost concern. When a person uses a wheelchair, they cannot be subjected to situations that may leave them injured, impaired, or stranded without help. With this in mind, the proposed solution has multiple safety features incorporated. When the user is maneuvering the wheelchair, self-balancing technology will ensure the chair remains upright at all times. Projects such as Boston Dynamics MABEL proves such technology is possible and could potentially be scaled up in the future (17). Other safety technologies incorporated into the wheelchair include emergency response functions that detect a crash or fall and automatically call the police, similar to functions available in the Apple Watch (18). The speed of the chair will also be limited to prevent accidental acceleration in indoor environments.

When the user decides to travel outdoors around their urban environment, they should connect to the “pod” portion of the proposed design. This pod provides additional range, stability, power, and safety. When the chair and the pod connect, the lithium-ion battery packs in the wheelchair unite with additional, larger battery packs in the pod. These batteries will add more power to achieve speeds more appropriate for city roads. The larger batteries in the pod will also charge the batteries in the chair to reduce the risk of the user running out of charge and being stranded. In addition to the batteries, a third wheel is activated to provide added stability for higher speeds. This third wheel also helps support the additional weight of the added materials used in the pod, including the safety bar.

The safety bar is the portion of the pod that keeps the user safe from frontal collisions. The retractable aluminum bar covers the users' arms, legs, and torso from fender-benders and low-speed collisions. Not only does the pod proved crash protection, but also provides an air-tight seal for the windscreen. The retractable windscreen protects the users' eyes from wind, rain, and debris that may come in contact with the vehicle. Hidden within the canopy will also be airbags that can surround the user in the case of more severe collisions. In the case of any collision, the same emergency-response detection would call 911 immediately.

Health

Feeling like a valuable member of society is tremendously important for citizens of dense urban environments. Factors for poor mental health include worrying about economic status, low frequency of socializing, and social segregation. These factors can lead to depression, anxiety, and even schizophrenia (19). People who use a wheelchair are presented with a unique set of challenges that can lead to all of these factors taking a hold of their life. By giving them a new, less intrusive way of navigating urban environments, the goal is to help more people feel included in our society as urbanization expands. By gaining the ability to have last-minute trips to work, restaurants, and social events, wheelchair users can be given more opportunities that otherwise would not have presented themselves.

Environment

A vehicle designed for the future is created, and the environment it operates in must be considered. The days of destroying the environment are over, and new technologies must be incorporated to prevent a climate crisis. The use of green materials such as reinforced composite and PLA polypropylene help replace the dependency on some of the most harmful petroleum-based materials used in vehicles. Metals such as aluminum used in the frame and safety features are recyclable and can even be made from reclaimed parts sourced from older vehicles. Last, and most importantly, the proposed solution will not feature a combustion engine of any kind. This reduces pollution in the city and ensures higher quality air for everyone surrounding the vehicle (20).

3.6 Innovation Opportunity

The opportunity for a new and different solution is vast. The current market landscape in both wheelchair design and urban wheelchair transportation is years behind the curve. Many developing technologies could be applied to the industry such as autonomous driving, computer A.I, and flexible structures that allow configurable layouts. There needs to be a solution that allows a physically challenged individuals to navigate urban areas whether they are indoors or outdoors. Through my literature review and benchmarking exercises, I have determined that there are no current solutions to this problem that impacts hundreds of thousands of Canadians. It is time to bring wheelchairs and wheelchair urban mobility into the 21st century.

3.6.1 Needs Analysis Diagram

The information in the prioritization grid below (figure 12) is drawn from the possible solutions in 3.2.2 and weighs the importance of each feature to the user.

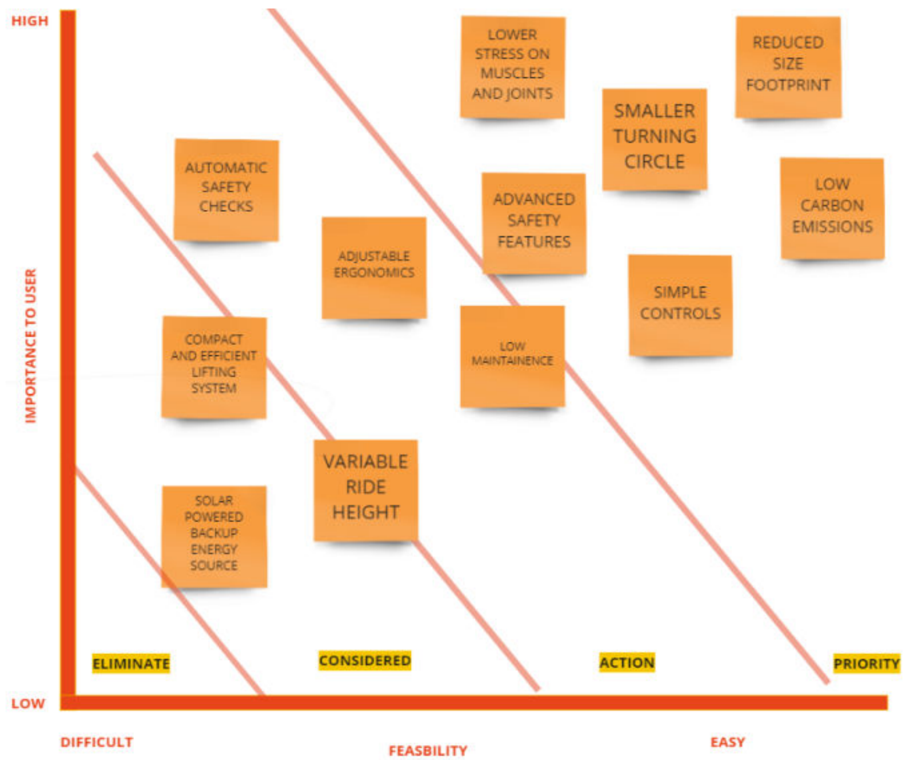


Figure 12 – Needs Prioritization Grid

Figure 12 includes solutions that satisfy needs as referenced in Maslow's Hierarchy of Needs (Figure 9). To meet the basic needs of the user, such as safety needs and physiological needs, the proposed solution must include features that lower stress on muscles and joints, as well as features that improve safety. Adjustable ergonomics and simple controls are features from benchmarked solutions that satisfy these needs.

To meet the categories of social and self-esteem needs, reduced size and turning circles allow the user to be less intrusive when attempting to travel crowded areas, and access more compact spaces such as stores and restaurants. By enabling the user to access these areas more easily, they may feel more confident going out and being confident in public. Self-actualization, which is the peak of Maslow's hierarchy, comes when all these features are combined to improve the user's overall quality of life.

3.6.2 Desirability, Feasibility, Viability

The desirability of the proposed solution will come from design, materials selection, and overall features that are useful. When designing something desirable, it helps to think outside the box and attempt to come up with something radically different. This creates space for innovation and can solve fundamental issues with current solutions. By choosing innovative and interesting materials, users can feel a sense of quality that also makes products desirable. Current solutions are often rugged and put function well ahead of form. Using design to better integrate materials, and using research to find more modern materials, new solutions can make users feel like the center of attention. Furthermore, useful features that cannot be found in any other solutions will also make users feel considered and empathized with. This will also draw attention to a product and make it more desirable.

The proposed solution is meant to be produced 5-10 years in the future, and therefore not all technologies and features will be feasible. However, in section 2.2.4 various emerging technologies and manufacturing processes were researched and benchmarked. These include the use of lightweight aluminum in the vehicle frame, reinforced eco-friendly composites for body panels, lithium-ion batteries, and PLA-based polypropylene plastics that use starch instead of petroleum. Some of these technologies have been proven in existing vehicles such as the aluminum frame and composite body panels, while others are emerging technologies that will be available shortly.

The market for wheelchair-accessible vehicles seems stagnant. The current solutions for urban transportation consist of busses, subways, or vans with complicated ramps and lifts. All these technologies are decades old and have not been designed from the ground up to accommodate wheelchair users. Instead of relying on public transportation systems that are rarely updated, young professionals should be able to purchase a cutting-edge vehicle of their own. This lessens the reliance on government funding of technologies and allows users to be independent. After all, creating independence for wheelchair users is the entire point of an accessible vehicle.

3.7 Design Brief

The goal of this thesis is to provide easy, last-minute travel options for wheelchair users in urban areas, thus reducing isolation and increasing independence.

Ergonomic seating and controls to mitigate long term pain for the user

Crash protection, anti-roll technology to ensure safety when alongside other vehicles

Ability to travel without planning so the user can explore their environment freely

Increased Indoor maneuverability to allow access to more areas

Comfortable and practical materials on the seating and controls to keep the user relaxed

Improve handling to make quick maneuvers indoors and outdoors

Make both indoor vehicles and outdoor vehicles complement each other

Interesting design and aesthetics to appeal to the modern individual

Power and materials that reduce Co2 emissions into the atmosphere and environment

Must be operated by a single individual, without assistance

CHAPTER 4: Design Development

The chapter below is intended to focus on the design journey of the proposed solution for urban wheelchair mobility. Beginning with products that inspired the aesthetics, this chapter will then cover mind mapping, idea generation, and general concept refinement. The sketches created digitally intend to show the concept clearly, with progression and refinement in each development stage.

4.1 Initial Idea generation

4.1.1 Aesthetic Approach and Semantic Profile

To gather examples of the intended design direction, various image sources were used. These images focused on the detailing of existing products rather than the product as a whole. This is because the proposed solution is intended to have unique design details unlike other vehicles and mobility devices.

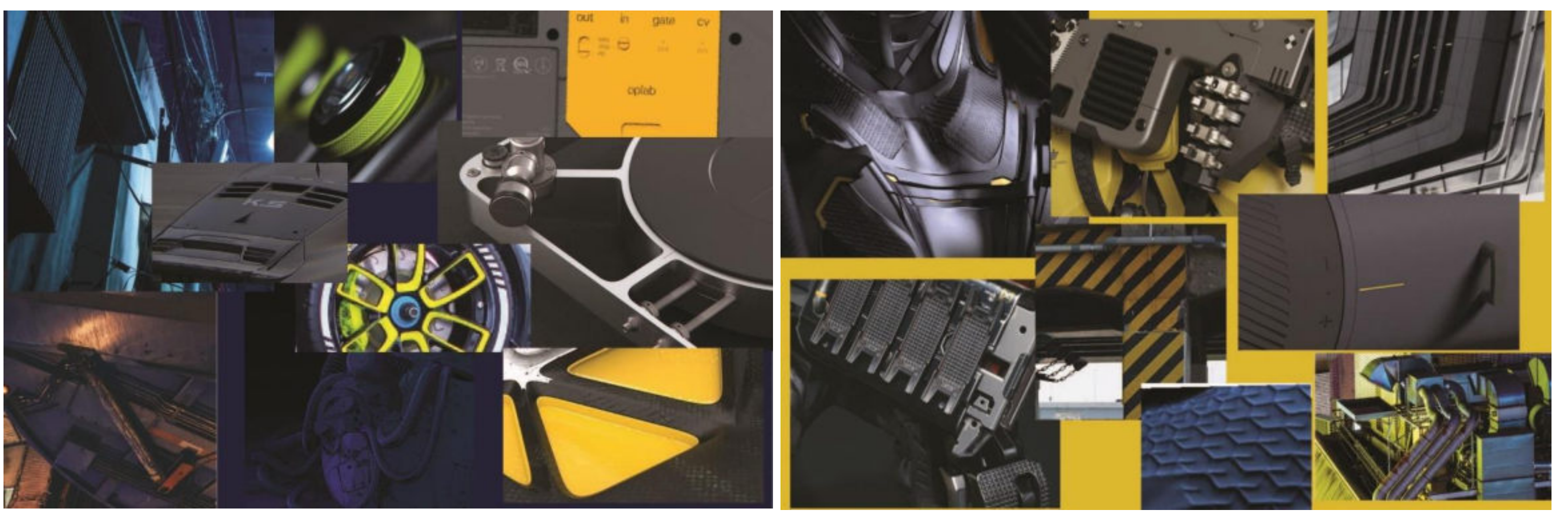


Figure 21

4.1.2 Mind Mapping

With the aesthetic approach established, the next stage is creating a mind map related to the problem definition. The map was divided into four categories, including users, feelings, technology, and environment. This was done to keep certain ideas in mind while creating ideation sketches.

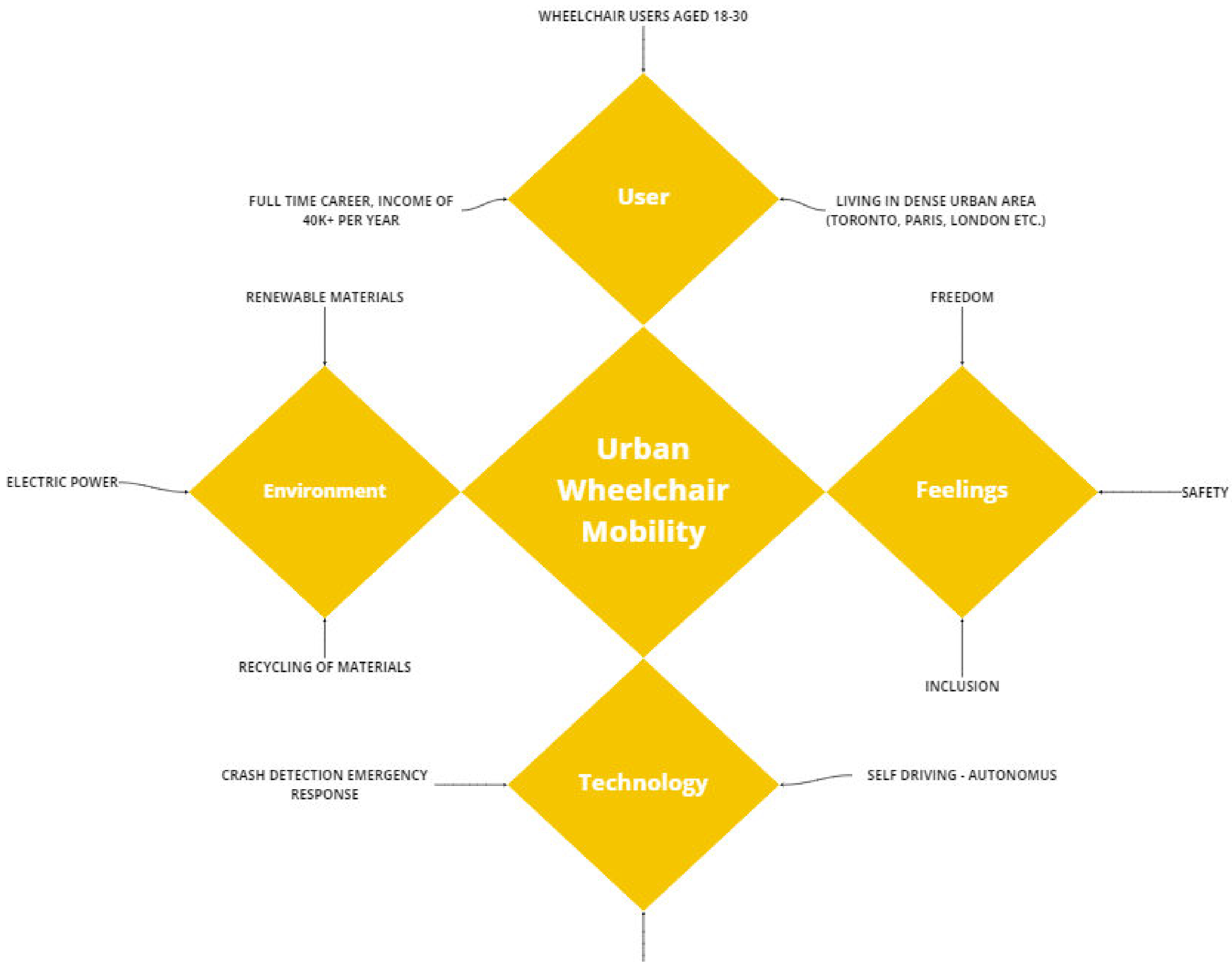


Figure 22

4.1.3 Ideation Sketches

The preliminary stage of sketching took into account the aesthetic approach and semantic profile, as well as the mind map, and created visuals related to urban wheelchair transportation. In this first round of sketching, various shapes and sizes of vehicles were thought of. The accessibility of each vehicle was also visualized in each concept. These sketches can be seen below.

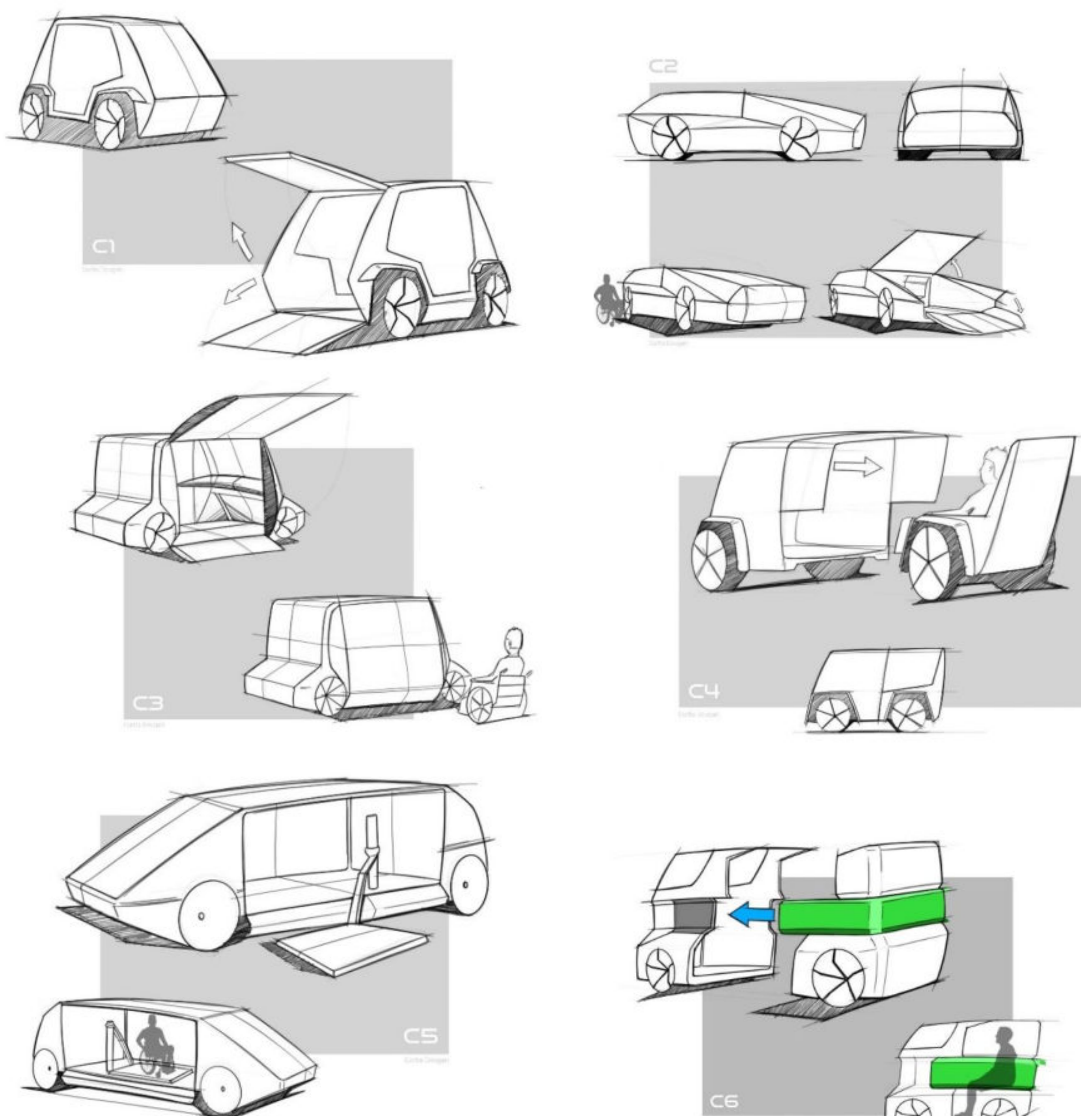


Figure 23

4.2 Concepts Exploration

After creating rough ideations, it was time to begin refining ideas based on feedback from professors and peers. These concepts more thoroughly explored new ideas and included more detail. Each concept will be described and shown below.

4.2.1 Concept One

The first concept is an indoor/outdoor vehicle with two wheels in the front and one wheel in the back. Each wheel is capable of moving to decrease the overall footprint or increase stability for driving in the bike lane.

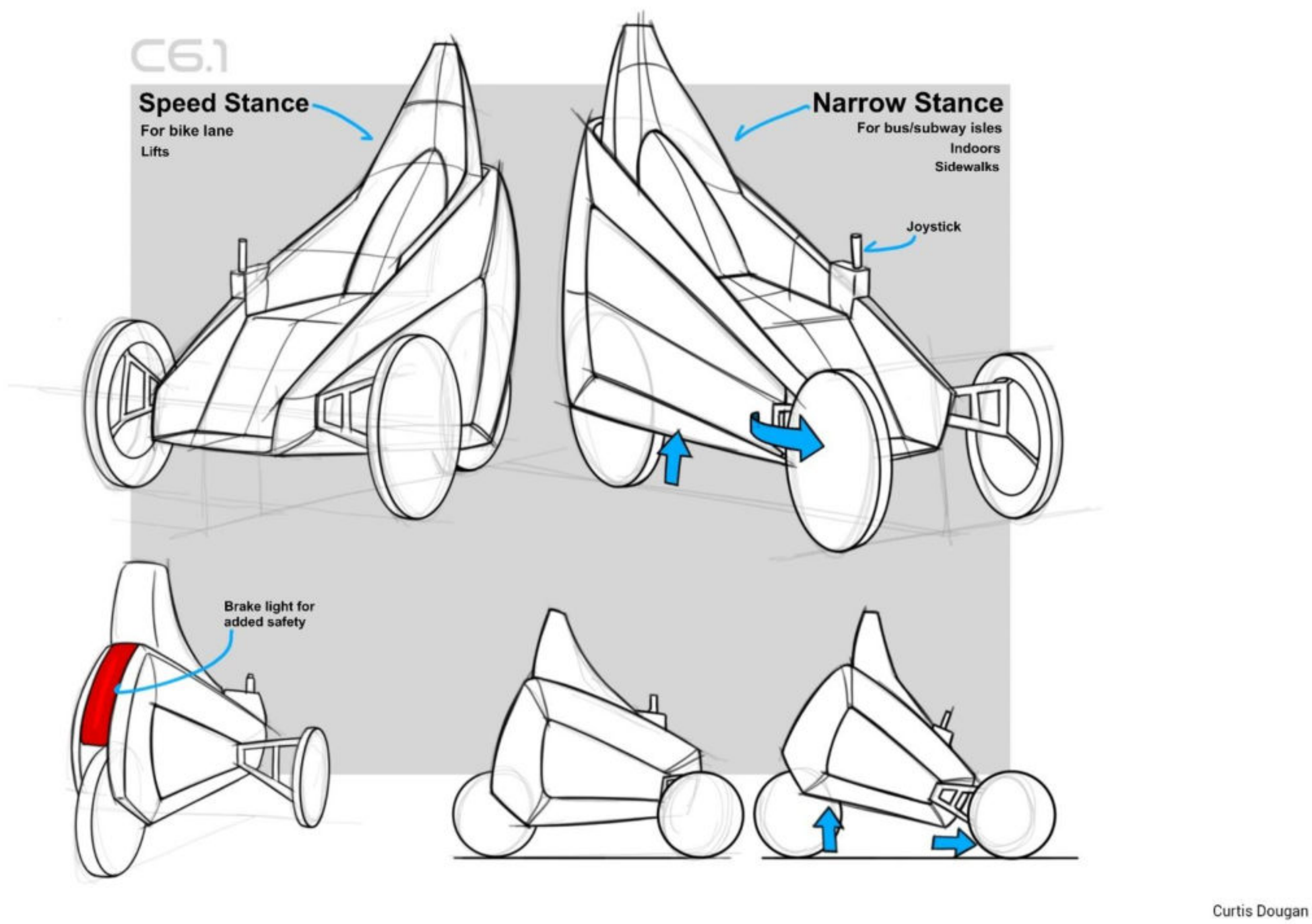


Figure 24

4.2.2 Concept Two

The second concept for a wheelchair-accessible urban vehicle is shown below. This vehicle features an extending canopy that created a weather screen for outdoor usage. There is also a display screen and arm-rest to create more comfort for the user.

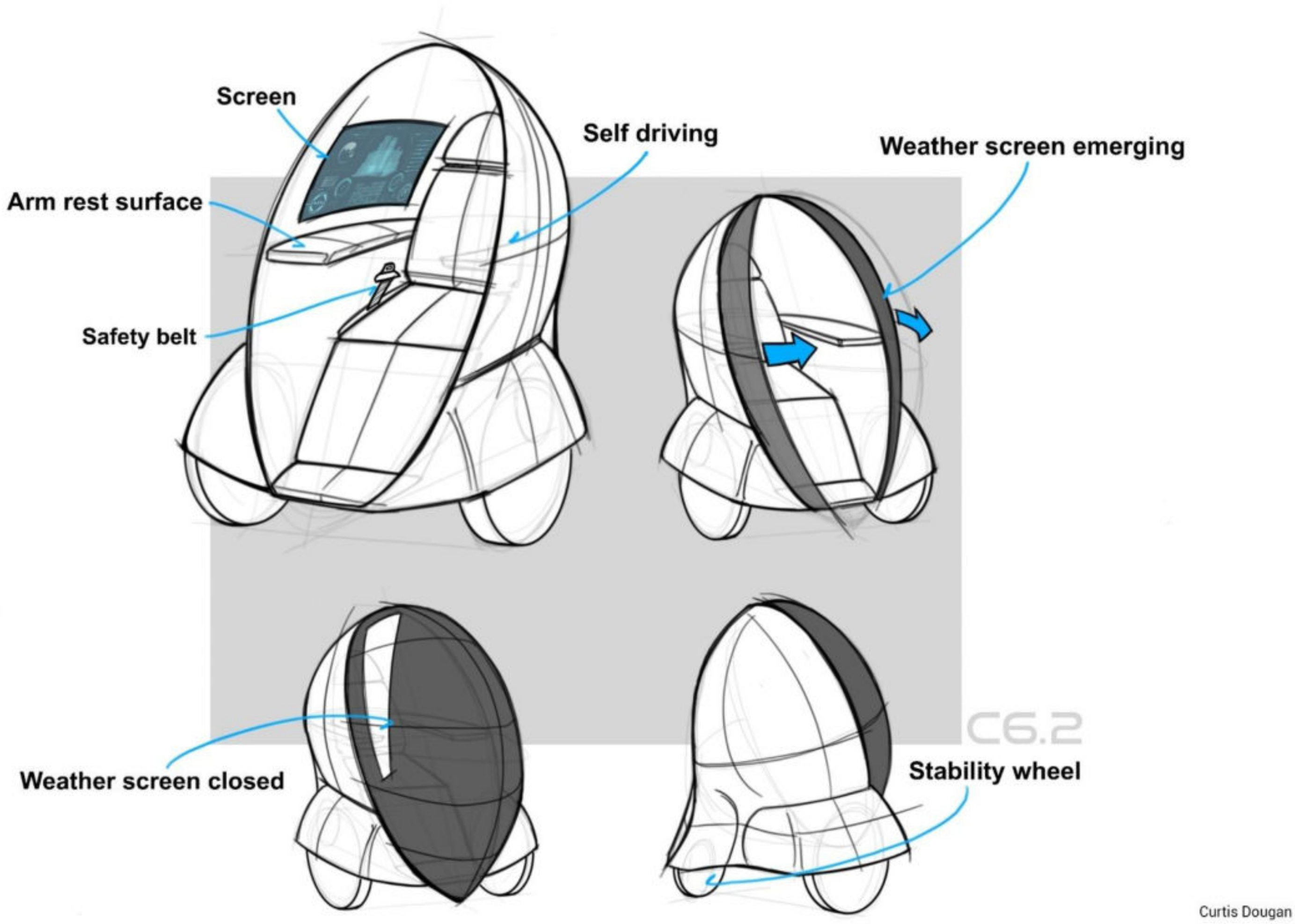


Figure 25

4.2.3 Concept Three

The third concept exploration shows a power wheelchair that drives into a rugged canopy to create a road-worthy vehicle. This vehicle connection results in added power, range, and safety for the outdoor environment. When the vehicles disconnect the chair is then capable of behaving like a traditional electric wheelchair.

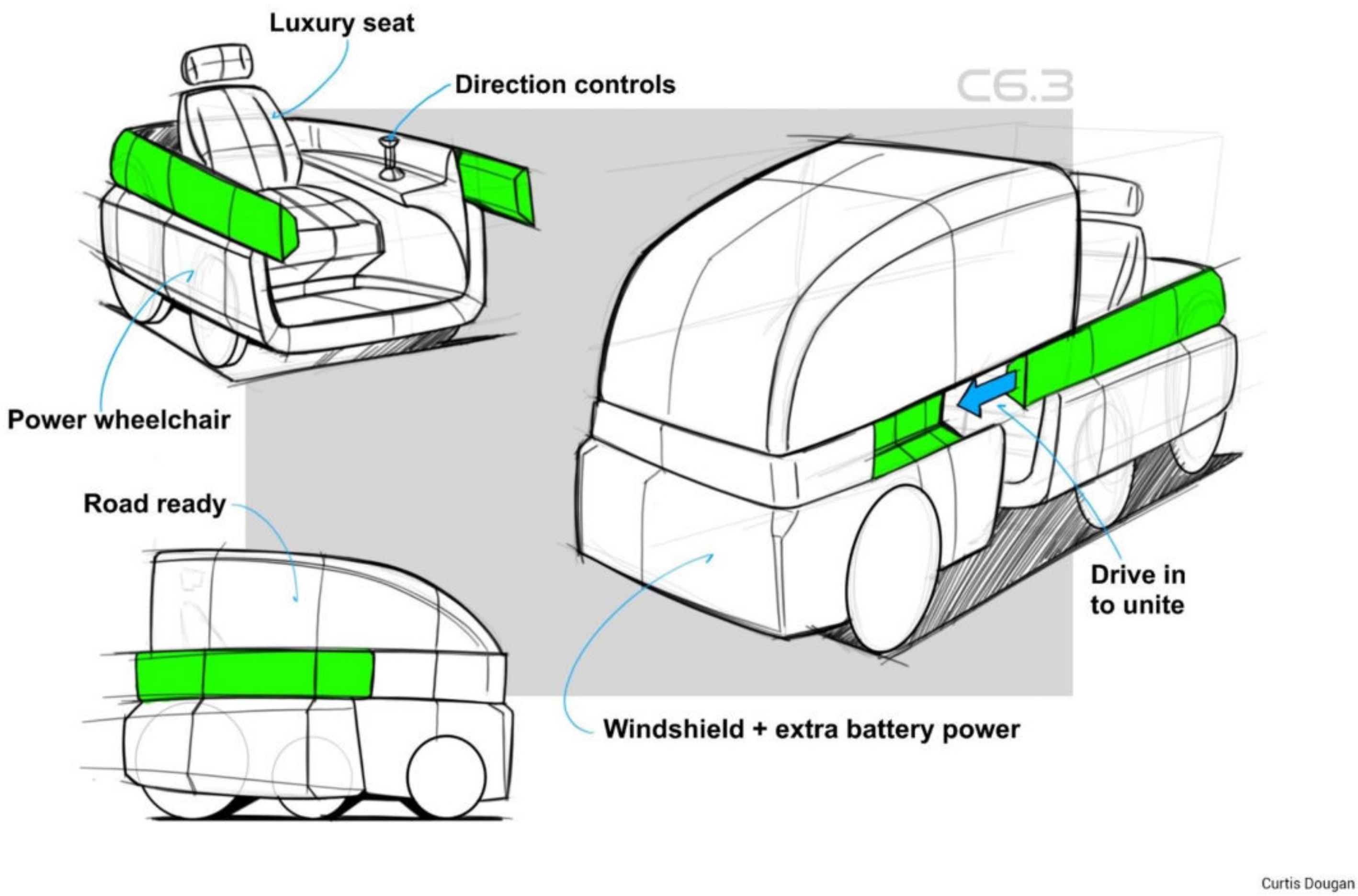


Figure 26

4.3 Concept Strategy

The previous section showed the rough creative process of designing an urban vehicle for wheelchair users. With the lessons learned from conceptualizing ideas, more refinement was still needed to continue narrowing in on a final solution. It became clear that the direction was going to be an indoor/outdoor vehicle that assists a user in all urban environments. The concepts proposed can be seen in the section below.

4.3.1 Concept Direction and Product Schematic One

The first direction proposed includes a two-wheeled, self-balancing electric wheelchair that features locking inner wheels to spin around in circles and navigate tight areas. This chair then connects to a “mother ship” that provides additional power, range, and stability for outdoor travel.

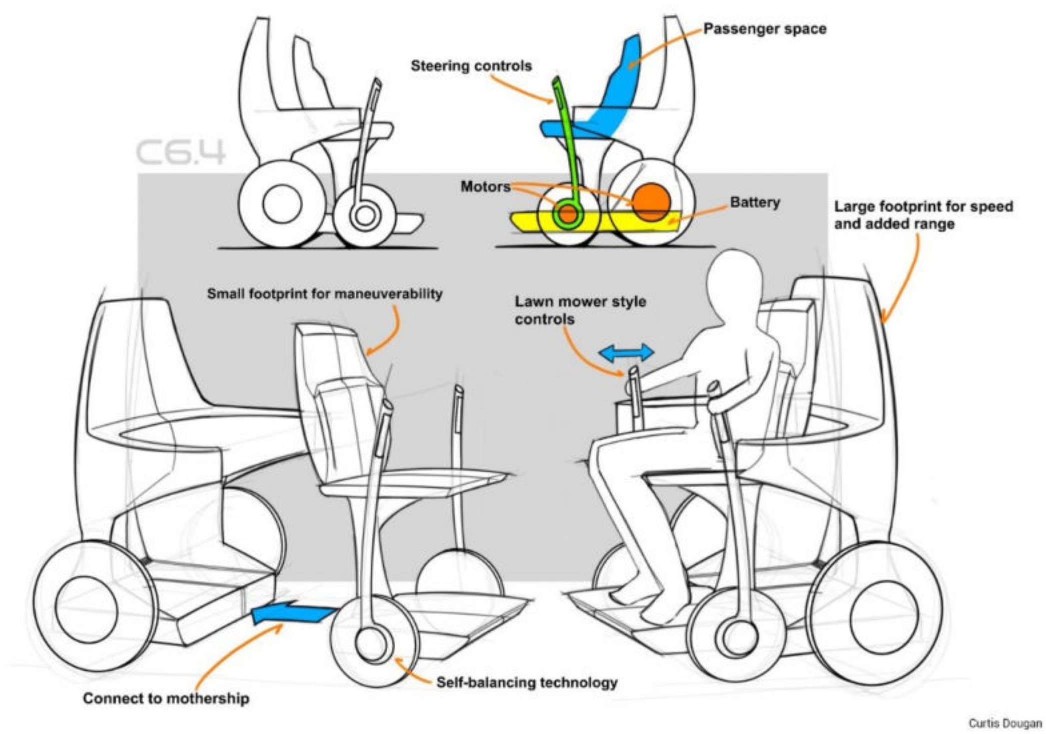


Figure 27

4.3.2 Concept Direction and Product Schematic Two

The second proposed direction features a more traditional powered wheelchair that enters the outdoor vehicle through the rear. This ensures full weather and crash protection for the user, as well as autonomous driving capabilities allowed by the inclusion of self-driving sensors.

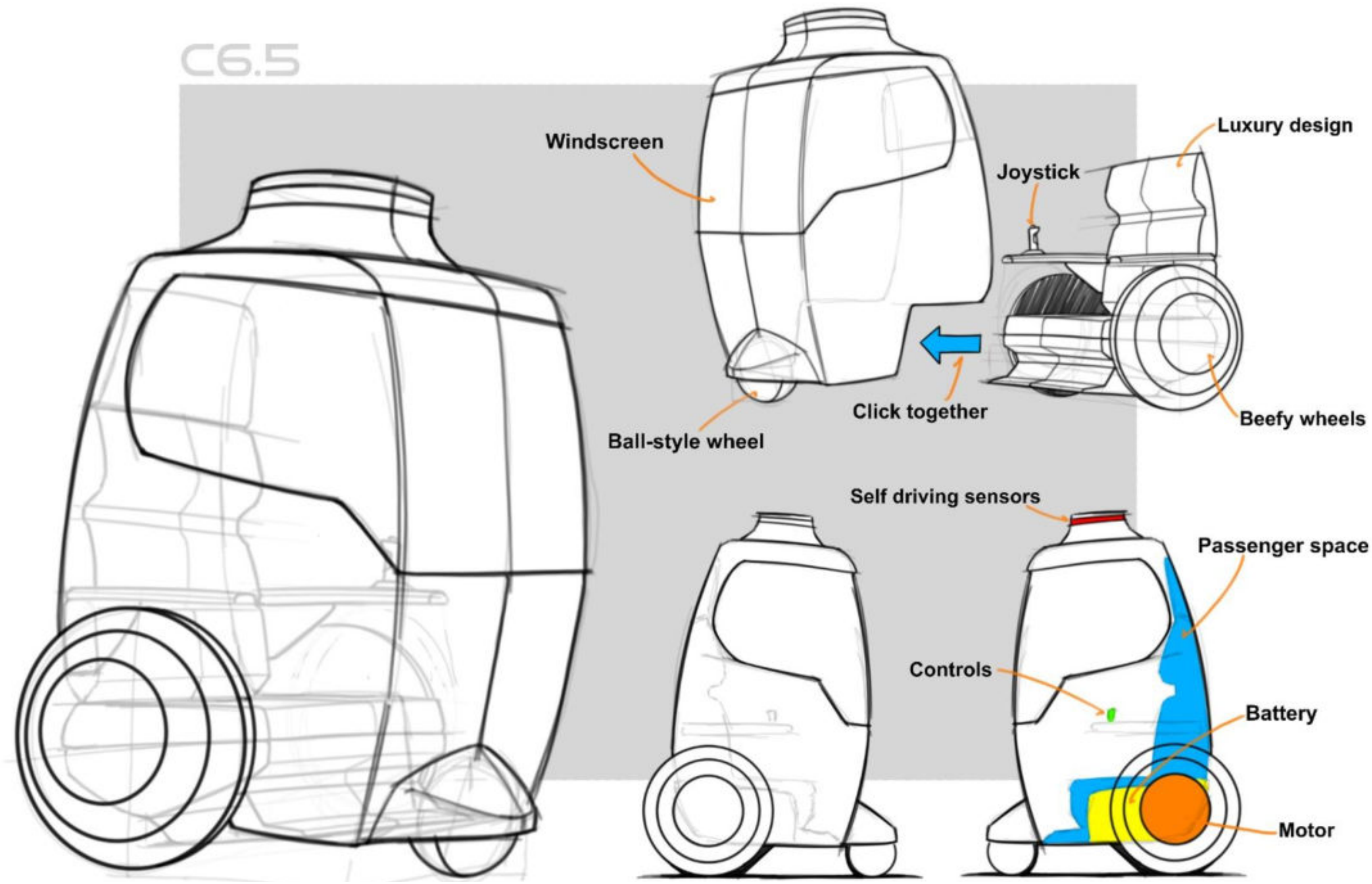


Figure 28

4.4 Concept Refinement and Validation

Learning from the two concept directions and semantics in section 4.3, a singular concept direction began to emerge. Features that carry over from the previous section are ergonomic controls, small footprint, electric power, and an indoor/outdoor element.

4.4.1 Design Refinement

The design direction is mostly based on the concept shown in section 4.3.1. However, many features have been refined and added. The self-balancing features and lawn-mower style controls carry over; however, they are better integrated. Larger wheels, an adjustable footrest, a headrest, and a new color scheme are all added as well.

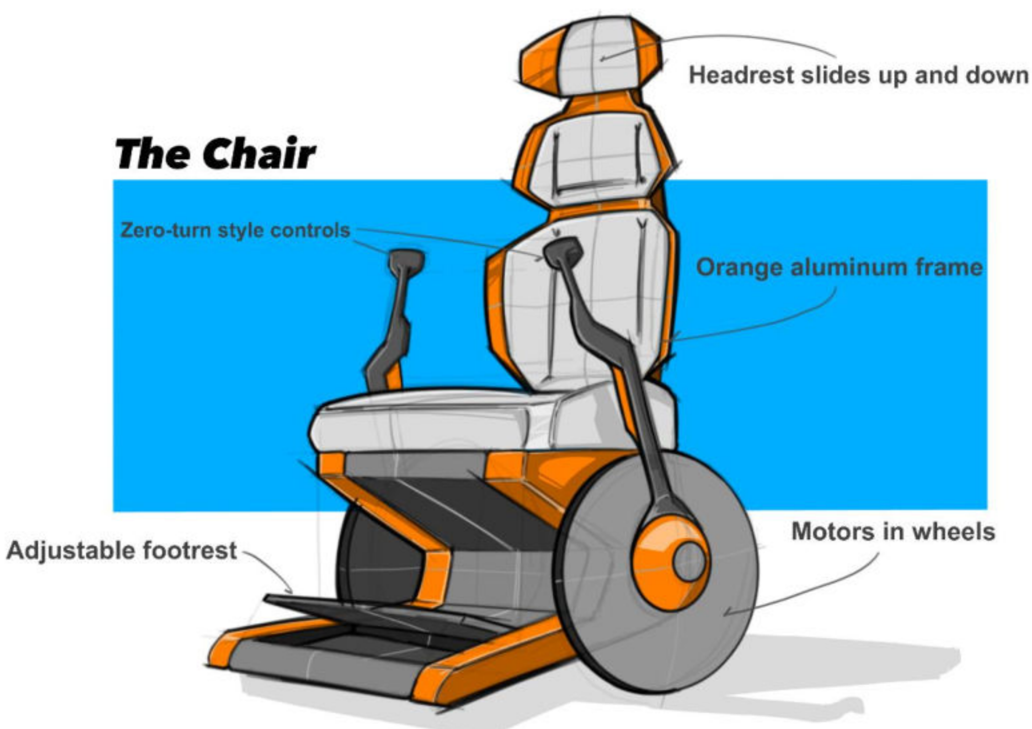


Figure 29

The self-balancing wheelchair is only the beginning of this concept, as there is an entire outdoor element as well. The wheelchair is intended to reverse into an outdoor pod that envelops them in weather and crash protection. This idea was a radical jump forward in the design process.

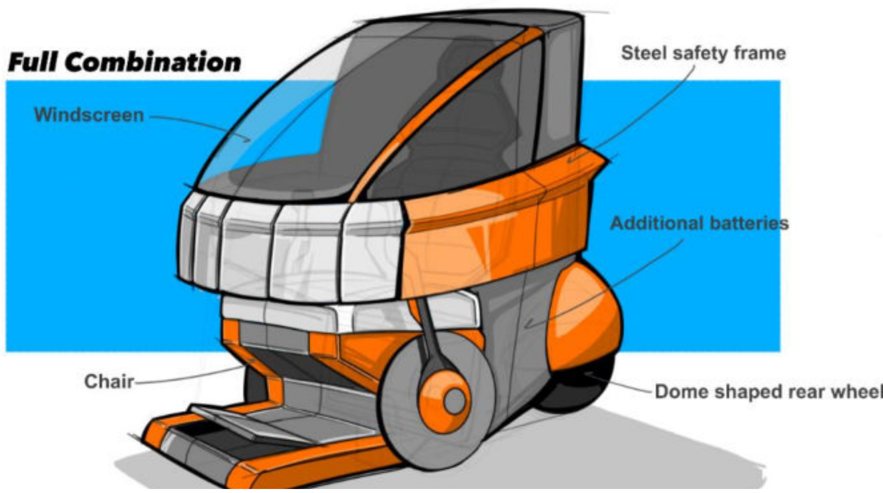


Figure 30

4.4.2 Detail Development

Detailed development of this concept included the operation of the wheelchair, the chair-pod connection, how the pod works, and detailed views of the wheels and hand controls.

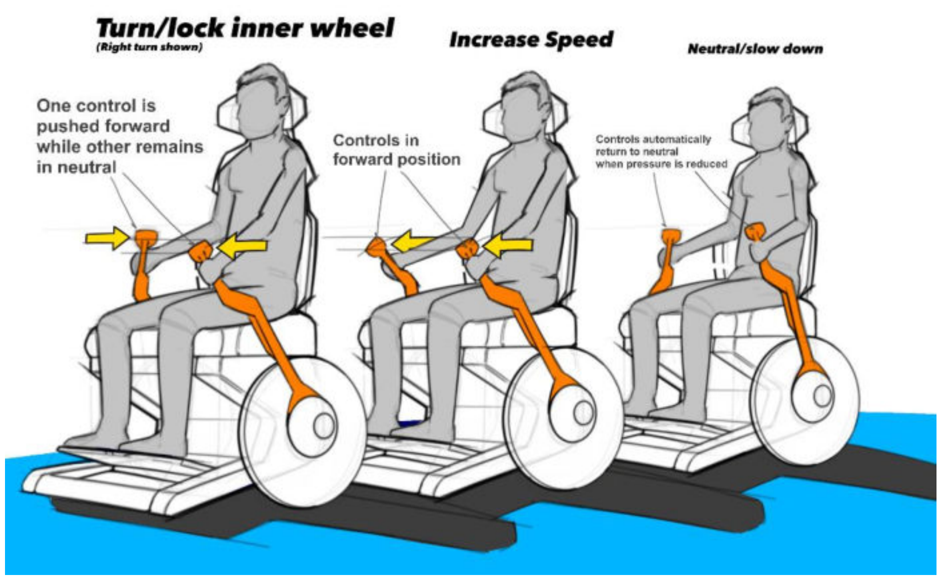


Figure 31

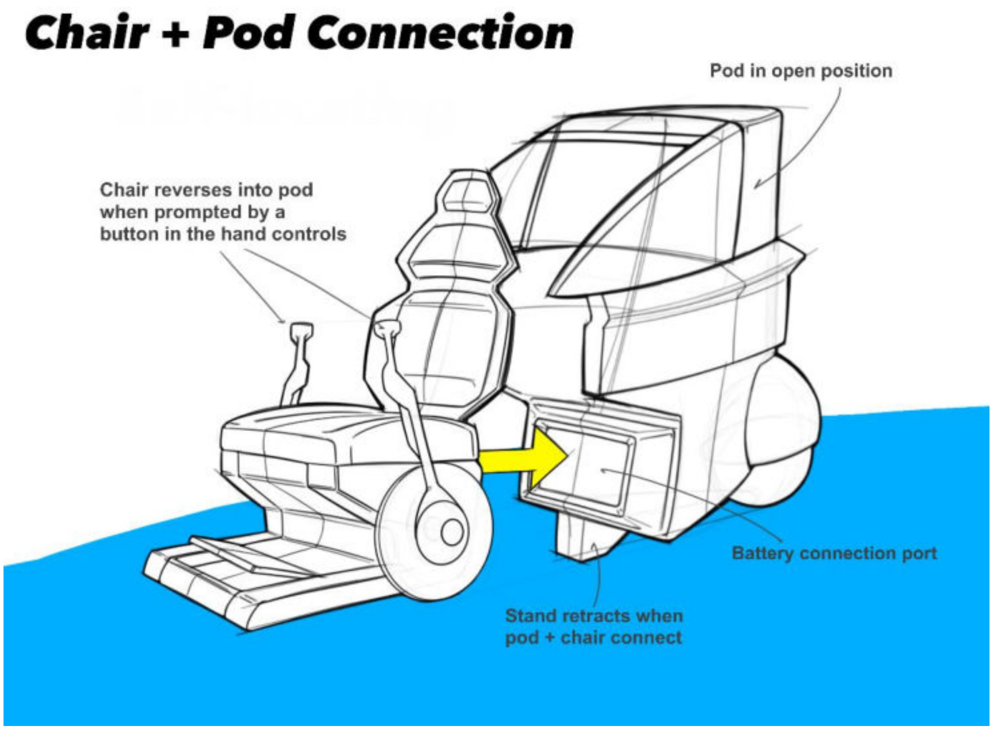


Figure 32

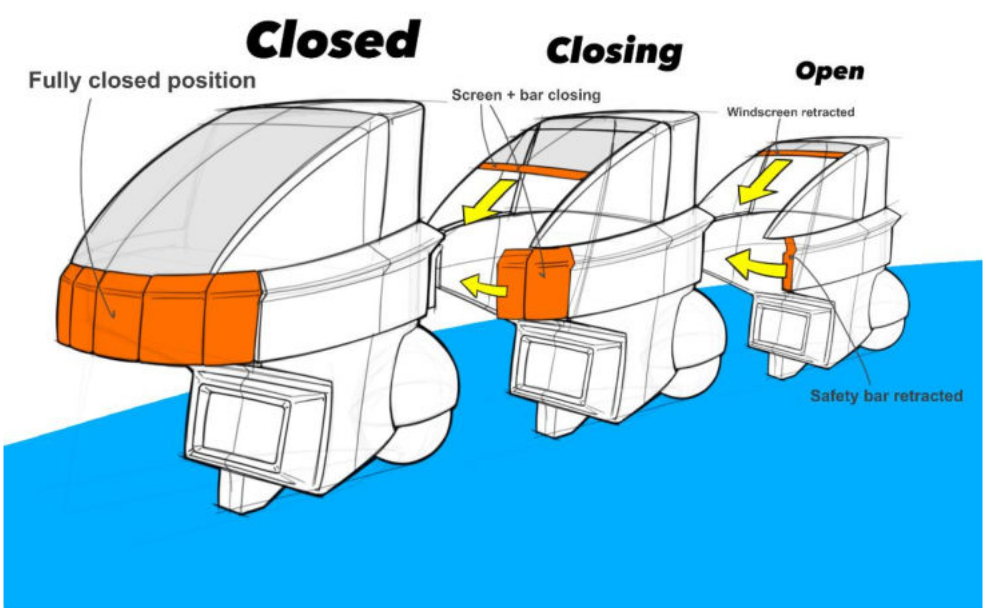


Figure 33

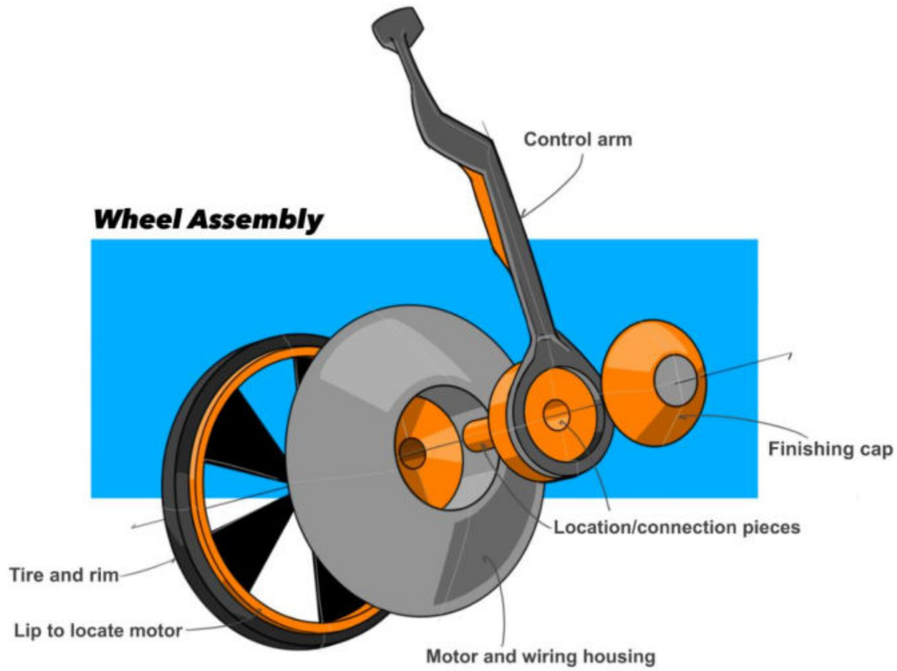


Figure 34

Hand Controls

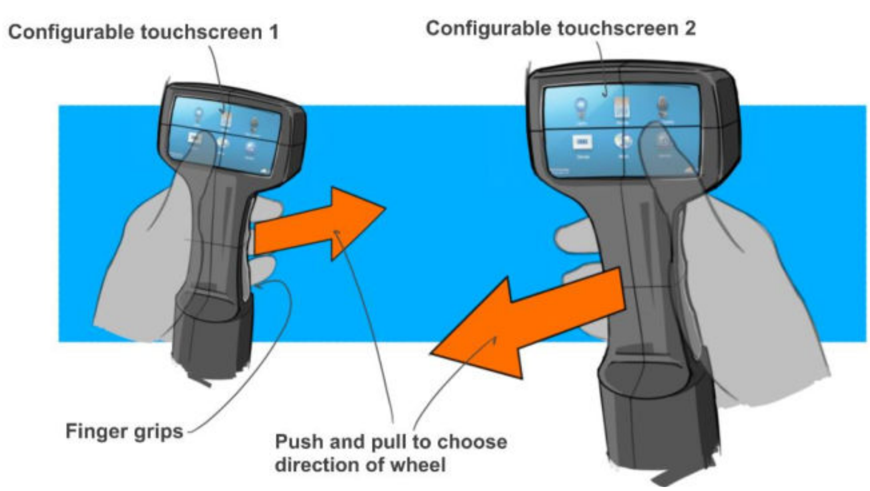


Figure 35

4.4.3 Refined Product Schematic & Ergonomics

To complement the refined concept direction, a new schematic and ergonomic study was done. Seen below is an updated version of the study done in section 3.3.1. Added to this schematic are an adjustable footrest, ergonomic arm controls, larger wheels, a wider stance, and a headrest. All of these features combine to create greater comfort for the user.

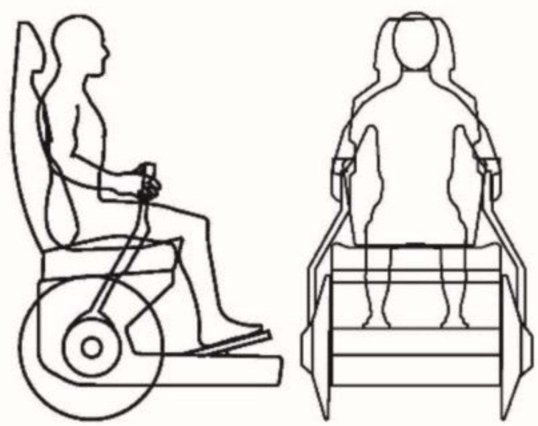


Figure 36

4.5 Concept Realization

This section is intended to finalize the size, features, and ergonomics of the concept. Included will be ergonomic dimensioning, and finalized front and rear views of the overall concept. This is not the final design of the concept, but it is close enough that CAD development can move forward afterwards, and the overall concept will remain unchanged.

4.5.1 Design Finalization

The following is the finalization of the design process. This showcases the overall features, color scheme, and ergonomics before advancing to the CAD development process. This design is intended to include full-body interaction, and includes contact points on the back, bottom, hands, and feet of the user.

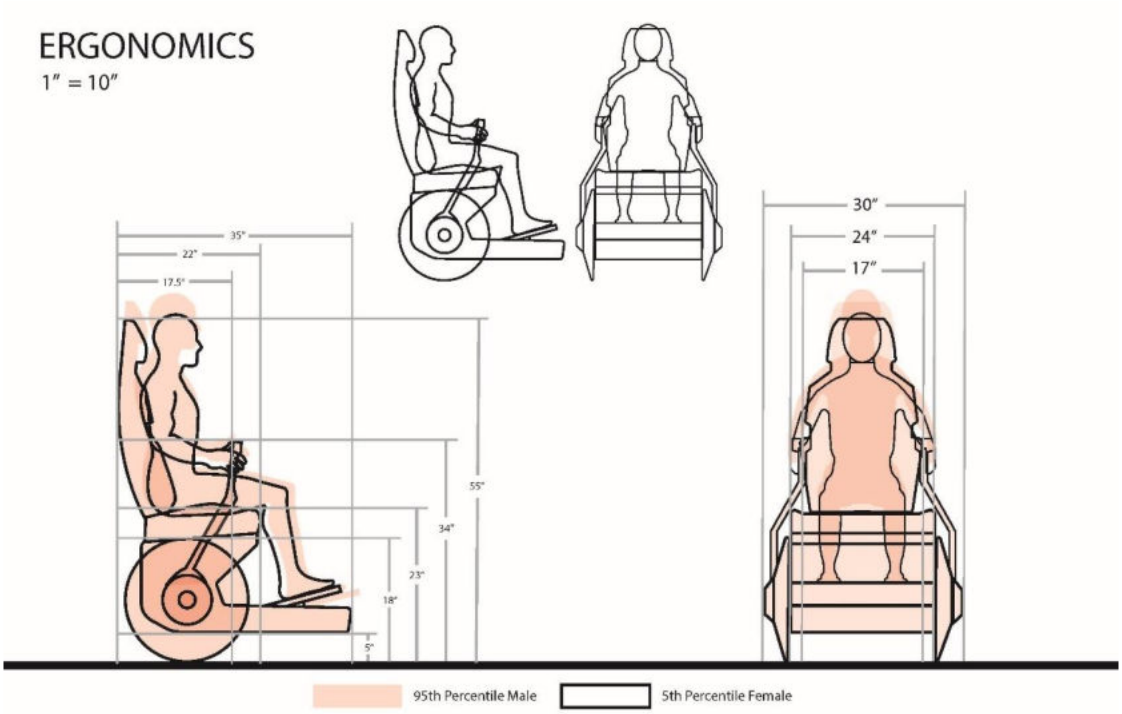


Figure 37

Figure 38

4.5.2 Physical Study Models

The physical model is intended to create a scale model of the concept shown in 4.5.1 in order to better visualize it. From this learning experience, further changes may be required to better realize the intended concept direction. The model was constructed using cardboard and glue.

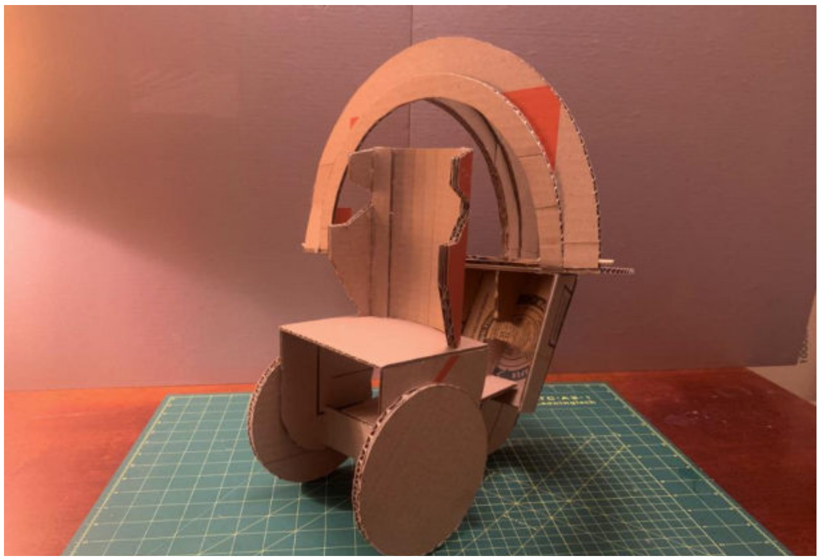


Figure 39

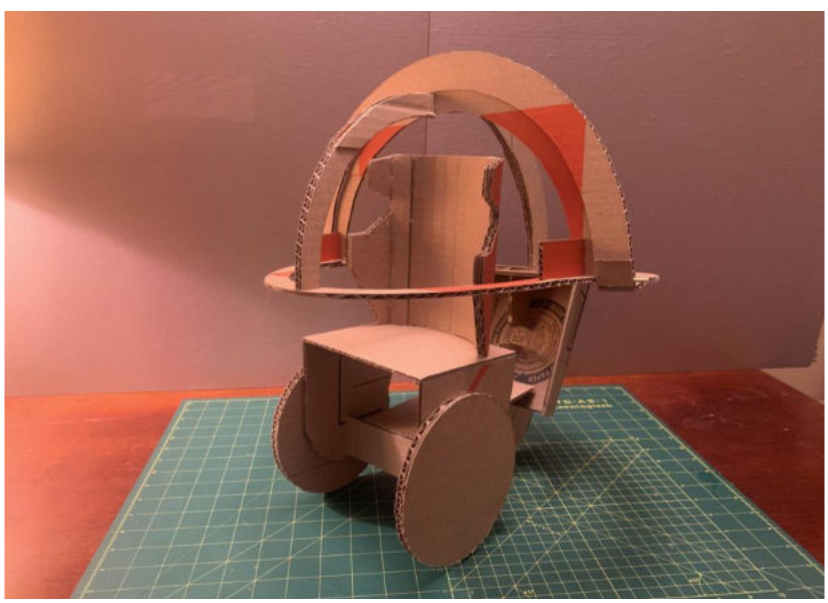


Figure 40

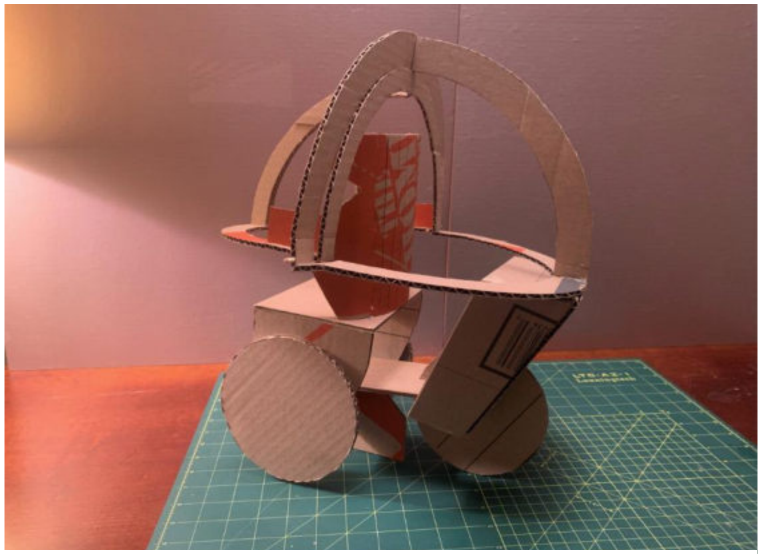


Figure 41

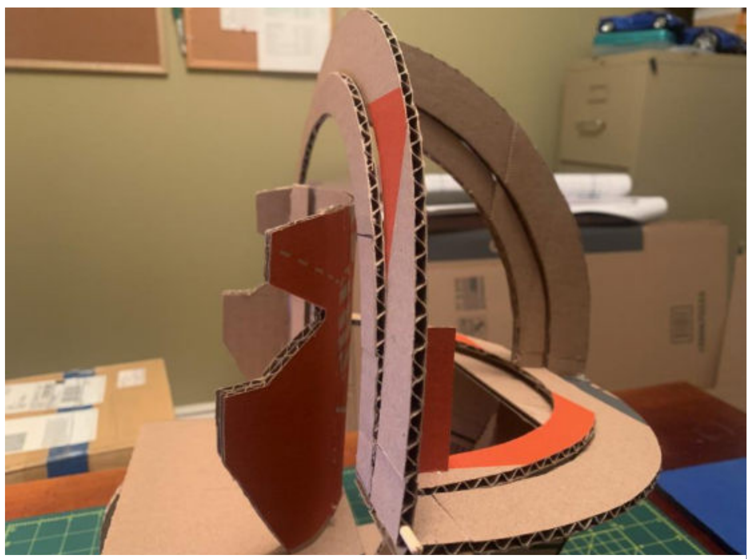


Figure 42

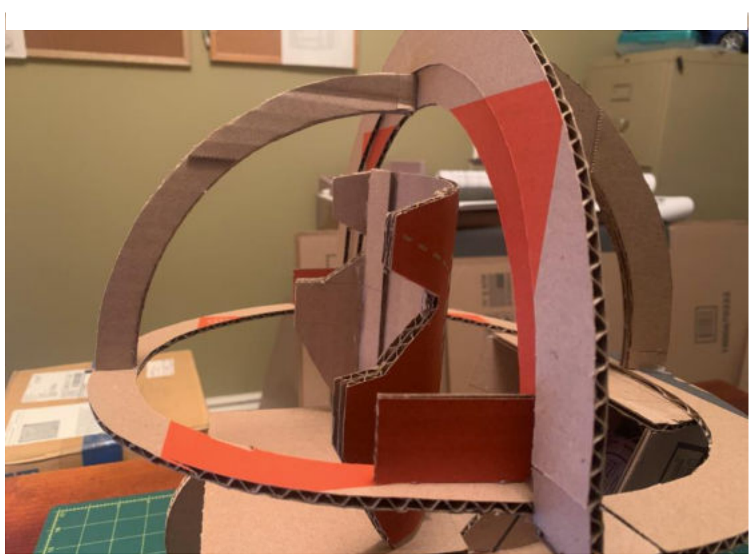


Figure 43

4.6 Design Resolution

The resolved solution for an urban commuting vehicle for wheelchair users includes a self-balancing wheelchair and a companion pod that surrounds the user with crash and weather protection. The wheelchair is to be controlled by two separate control arms attached to electric motors housed in the wheels that dictate the direction of spin. Other controls are to be located on the top of the control arms and near the users' hands. Construction of the wheelchair and pod are intended to be reinforced composite or aluminum, depending on location. The wheelchair is to be finished in orange and have recycled fabric for the seat cushions. LED lighting is located on the front and rear of the companion pod to ensure road safety. The power source of the intended solution will be lithium-ion batteries, with the wheelchair charging its batteries when connected to the companion pod.

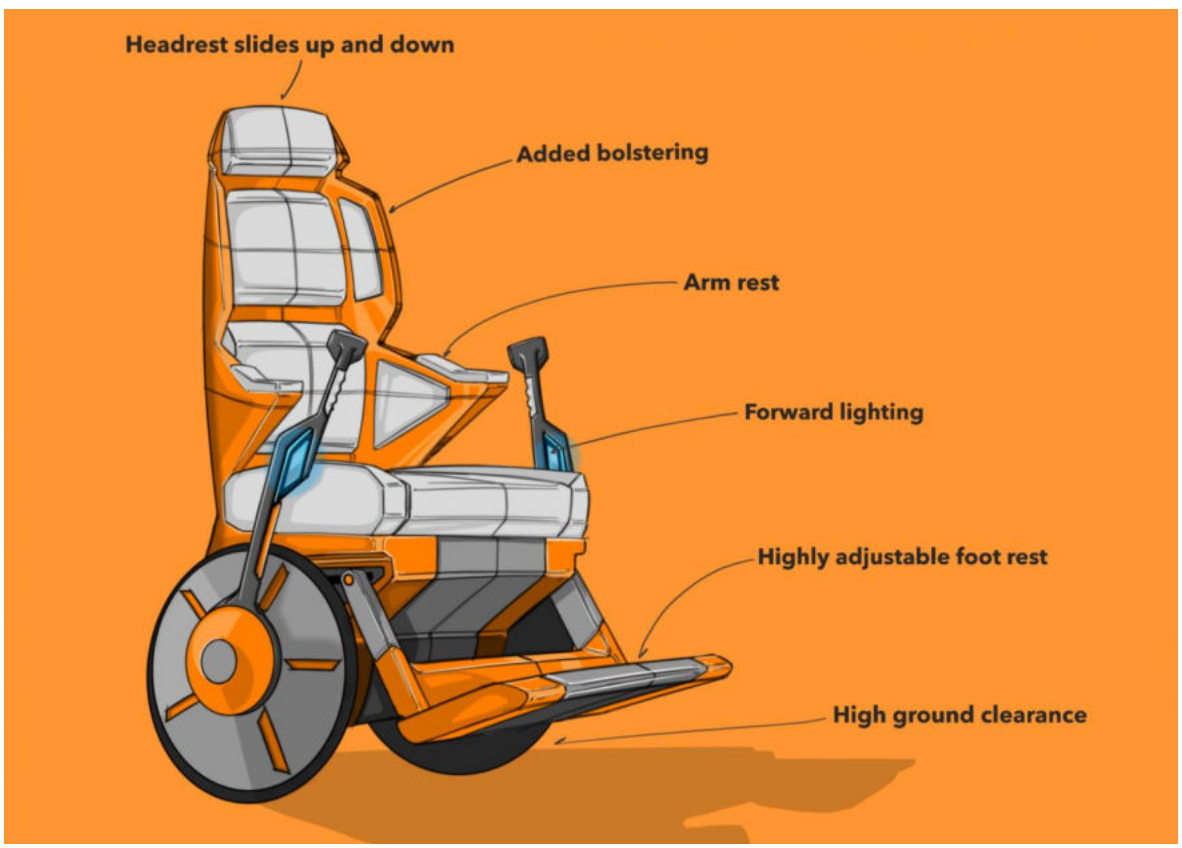


Figure 44

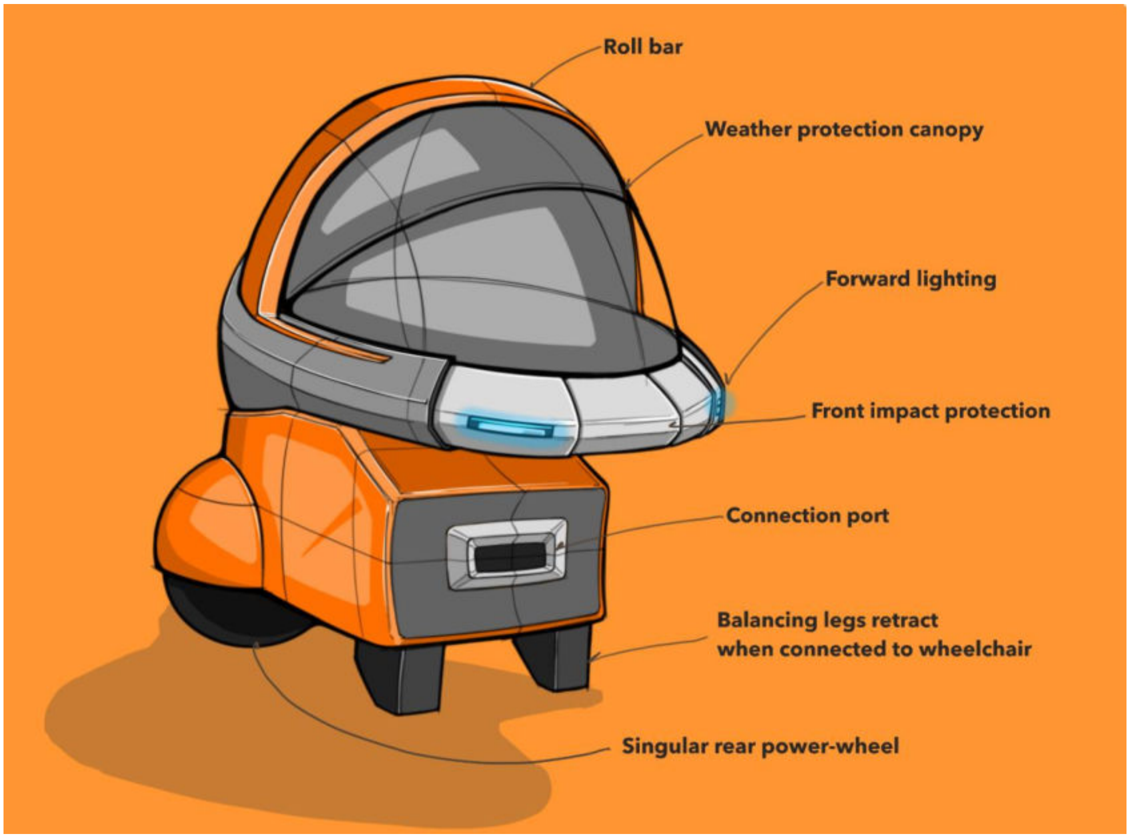


Figure 45

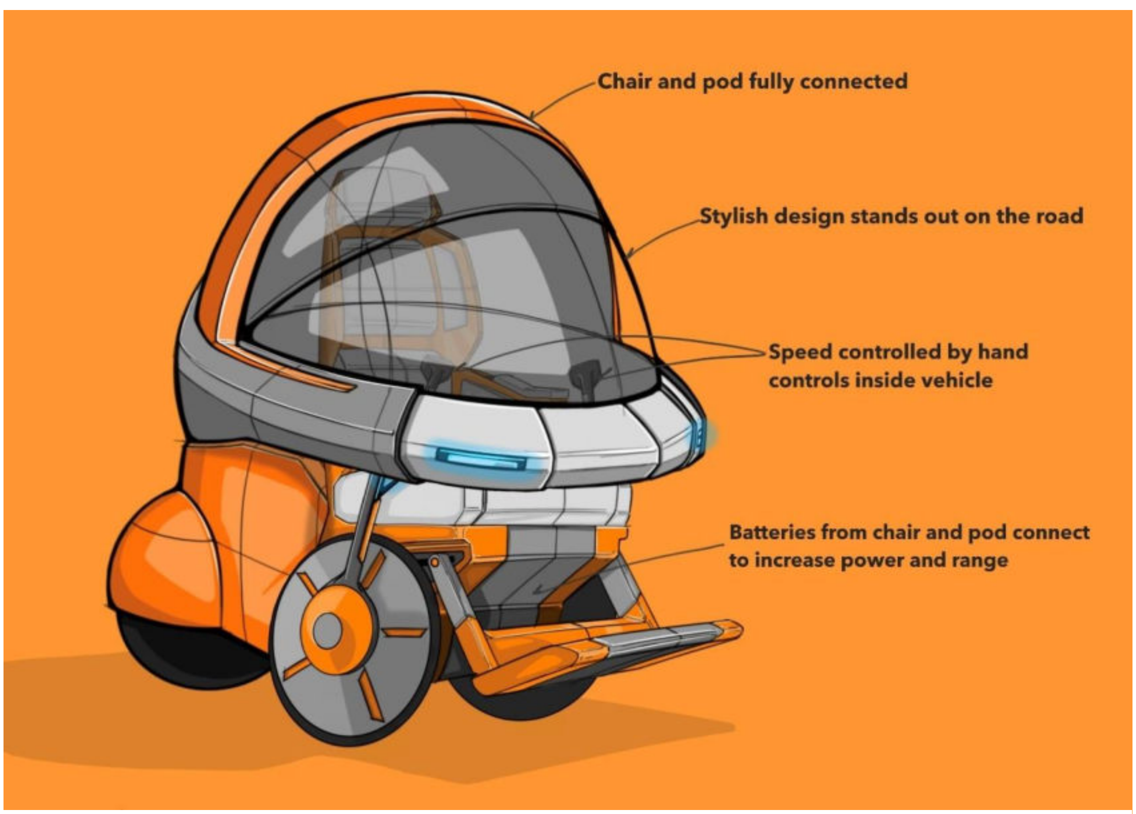


Figure 46

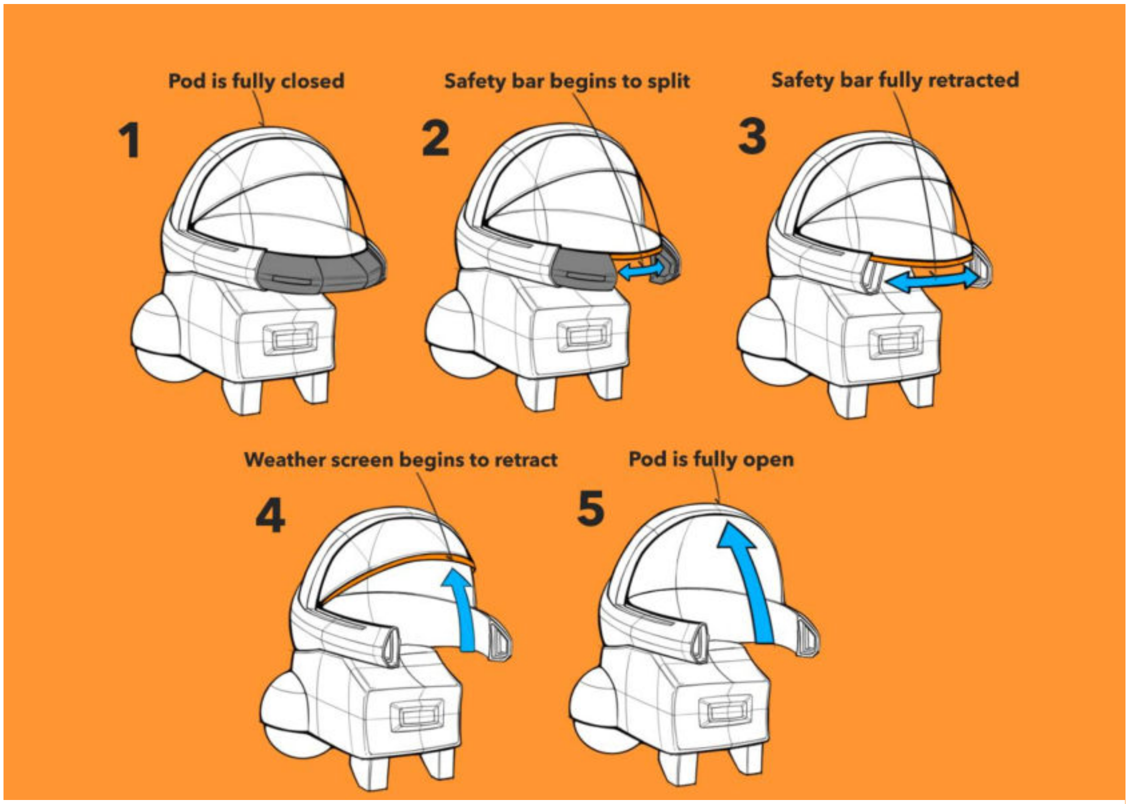


Figure 47

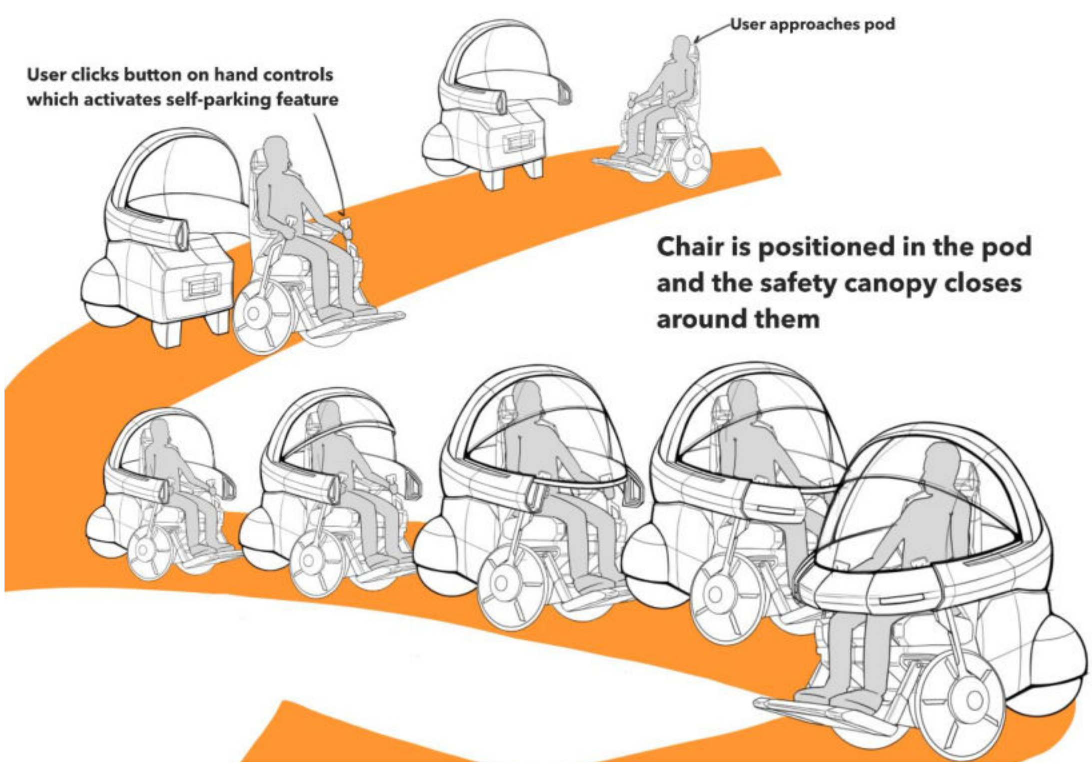


Figure 48

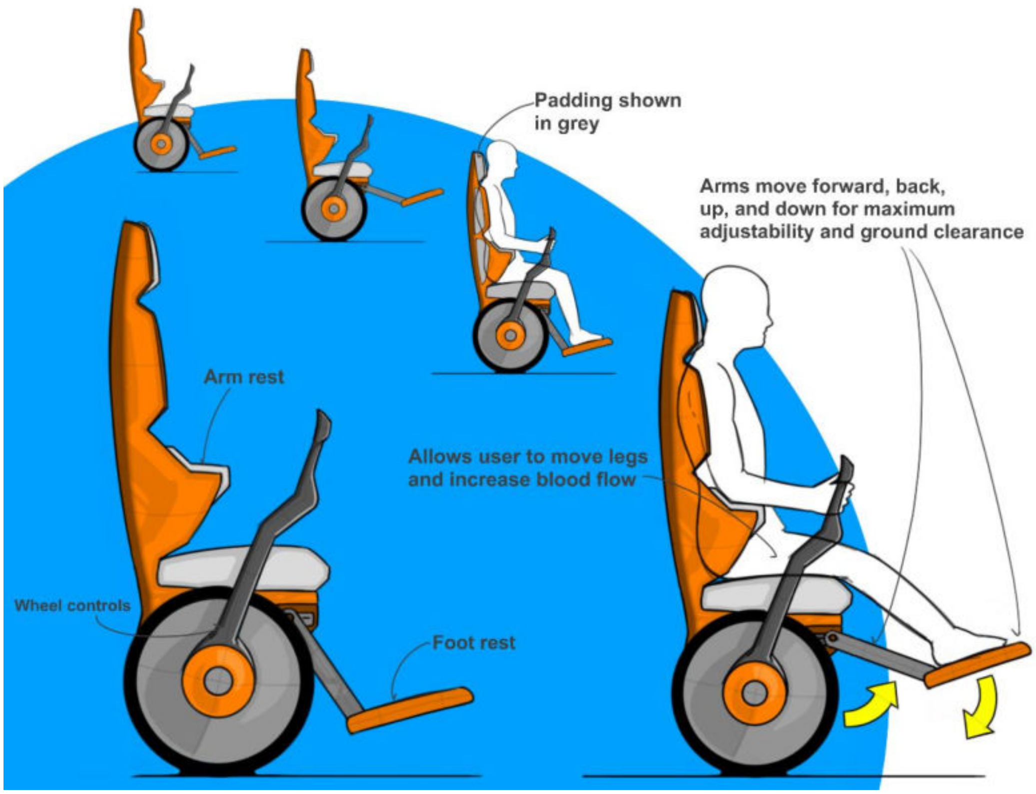


Figure 49

4.7 CAD Development

With the design finalized for the urban commuter vehicle, the CAD development process was set to begin. The program used to create the CAD model was Solidworks, and the first step in the process was bringing the design drawings in section 4.6 into the program and scaling them using the measurements found in section 4.5.1. CAD development started with a rough model to learn more about the dimensions and overall form of the model. This model was created using rough shapes and little detail.

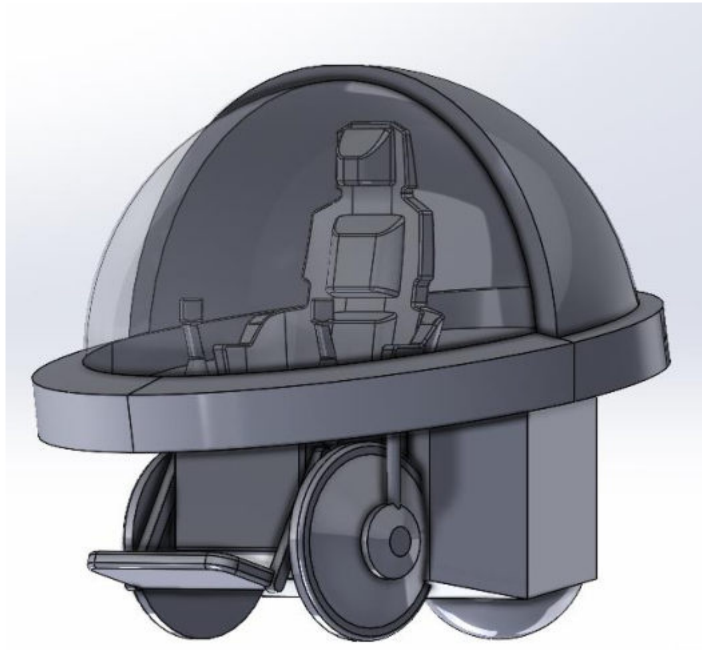


Figure 60

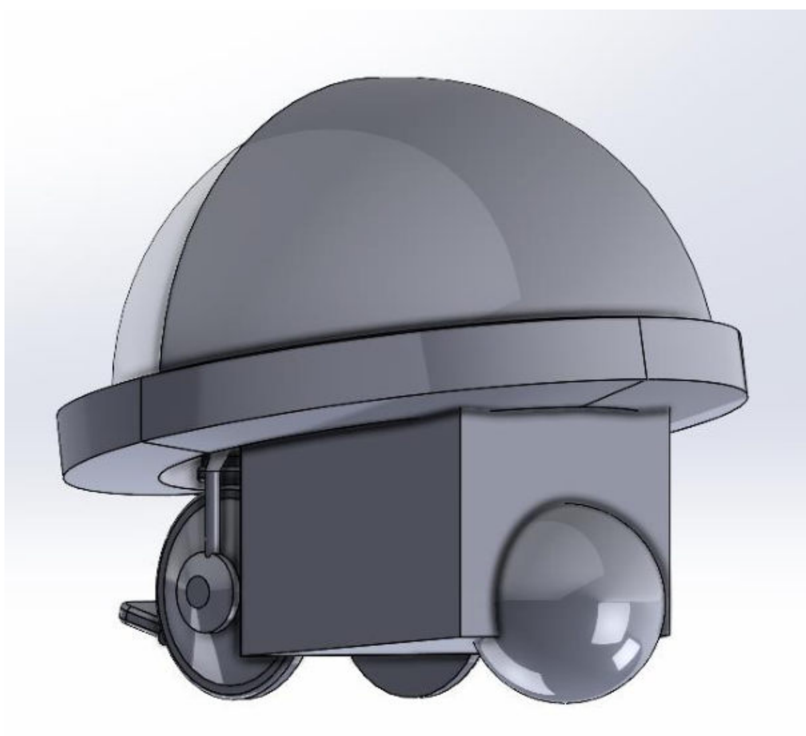


Figure 51

Figure 52

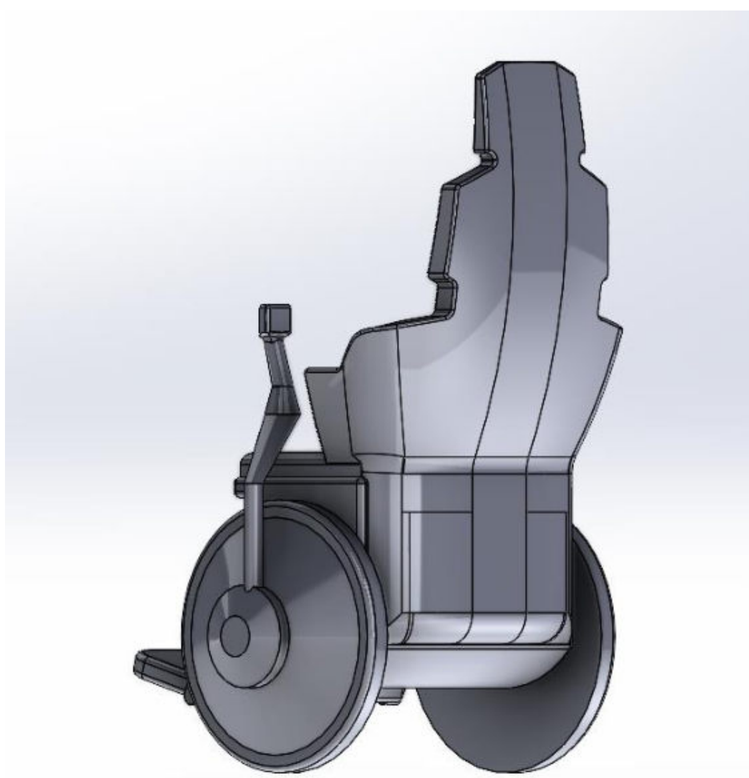


Figure 53

The next stage of CAD development was intended to refine the model and add more detail. At this point, it seemed that additional thought was needed to make the concept more feasible, so the wheelchair added revised self-balancing technology that is more accurate to real-world technology. This included electric motors housed in each wheel, and joints in the mechanism that move up/down, and forward/back to ensure the chair is always on two wheels. The pod was also updated to better reflect the design drawings.

Figure 54

Figure 55

Figure 56

Figure 57

With the model beginning to take shape, the CAD development was almost complete. Further refinement was required in order to make the design more aesthetically pleasing, as well as ready for 3D printing. Other additions included LED lighting as seen in the design sketches, more detailed motors and controls, as well as a revised orange color scheme. The project now has a name, which is PIVOT, that can be seen on the front bumper of the vehicle.

Figure 58

Figure 59

Figure 60

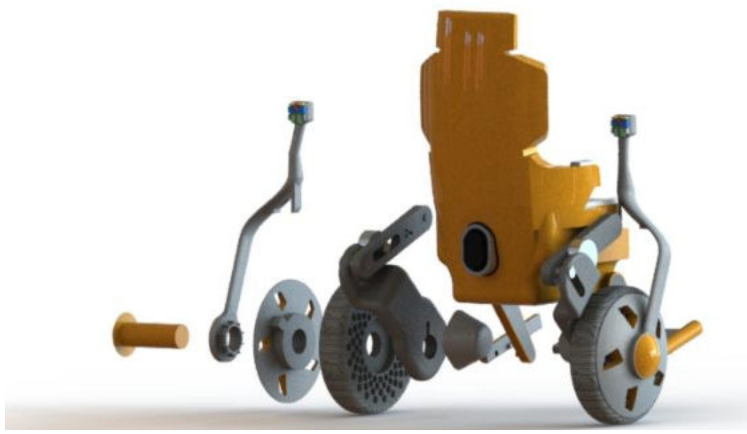


Figure 61

Figure 62

4.8 Physical Model Fabrication

CAD development is now complete, and a physical model of PIVOT is to be created. The model is 3D printed using the SLA printing method, as well as the SLS method. Each part was designed in CAD to have locators to ensure a solid connection between pieces. Once printed, the parts were sanded, primed, wet sanded, and finally painted and assembled.

Figure 63

Figure 64

Figure 65

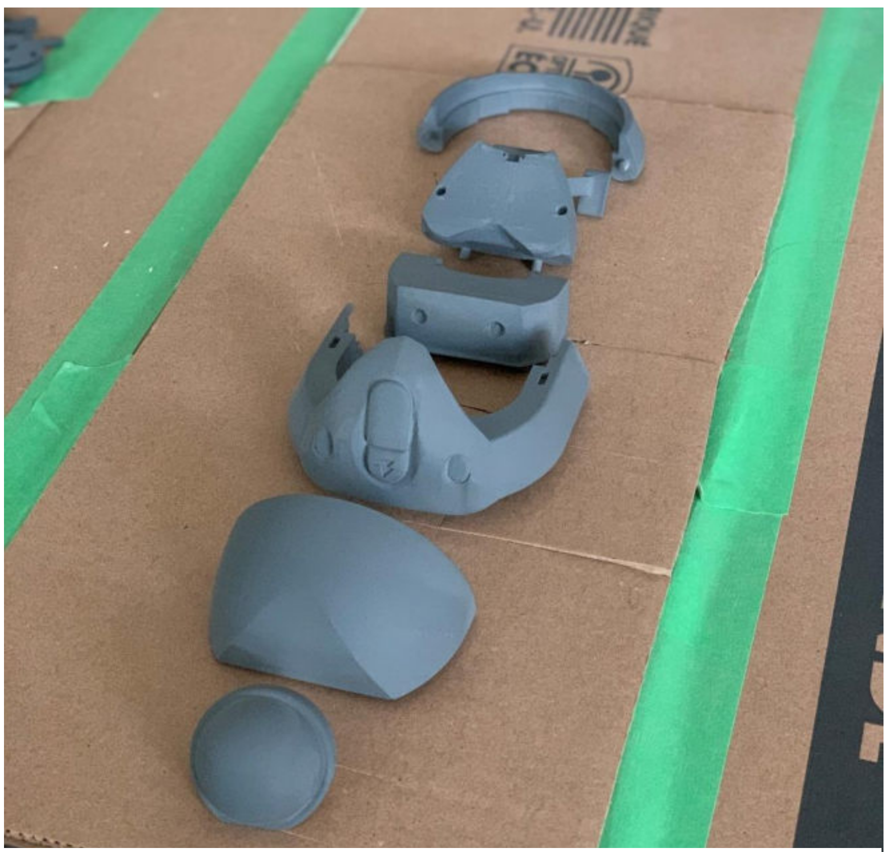


Figure 66

Figure 67

Figure 68

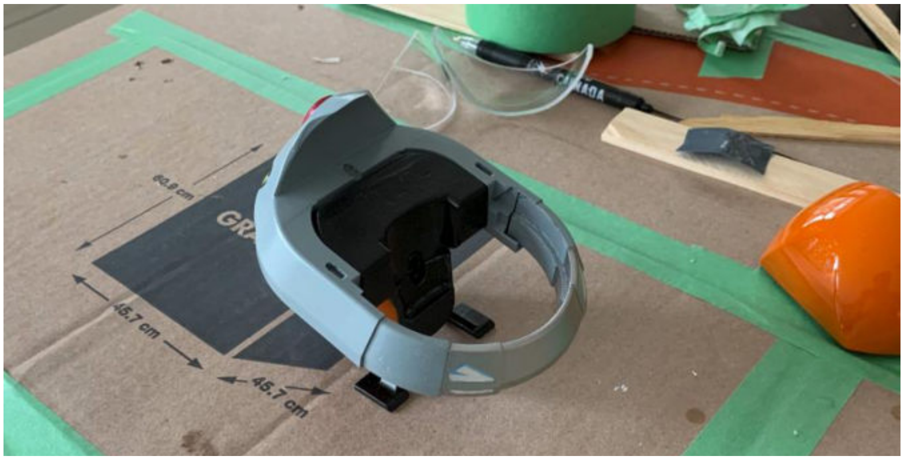


Figure 69

Figure 70

Figure 71

CHAPTER 5: Final Design

5.1 Summary

Description

Pivot is an electric-powered urban vehicle for the differently-abled with a detachable wheelchair, as well as retractable crash and weather protection. Pivot is intended to be used for short distances in urban outdoor environments, as well as in indoor environments when the wheelchair is detached from the main pod.

Explanation

Existing vehicles for wheelchair users in urban areas are often retrofits of existing vehicles that are not designed with wheelchairs in mind. This means they are large, inefficient, and dated. PIVOT solves this issue by being a small, efficient electric vehicle that can be entered without ramps or lifts. By being easy to enter and exit, wheelchair users will feel that traveling in the city is not a hassle, thus increasing their confidence and reducing isolation. After the outdoor trip, the challenges are far from over. This is why the self-balancing wheelchair has technology that allows users to effortlessly maneuver indoor environments with minimal stress on muscles and joints.

Benefit Statement

Differently-abled individuals do not have the freedom of transportation offered to able-bodied users. Options such as wheel-trans, subways, and buses are difficult to maneuver due to urban population density and traffic. While transit systems are making changes to retrofit existing solutions, these changes are still not enough. In fact, some solutions may be doing more harm than good. When using a wheelchair ramp to enter a vehicle or building, an individual could have 2-3 times their body weight on their shoulders. This could lead to injury, potentially isolating the user further. Additionally, a tremendous amount of planning is necessary to schedule pickup and travel times. PIVOT intends to be a safe, efficient, and convenient indoor/outdoor vehicle that allows the differently-abled to navigate the city with freedom and ease.

5.2 Design Criteria Met

The design criteria that must be met by this thesis project includes full-bodied interaction design, materials, and technology, as well as design implementation. The section below will highlight how PIVOT satisfies these requirements.

5.2.1 Full Bodied Interaction Design

PIVOT is designed to make the user as comfortable as possible because wheelchair users spend most of their time sitting. While sitting in the chair, the user is cocooned in padding to ensure that they are stable when turning corners, and do not have any hard surfaces to injure themselves on.

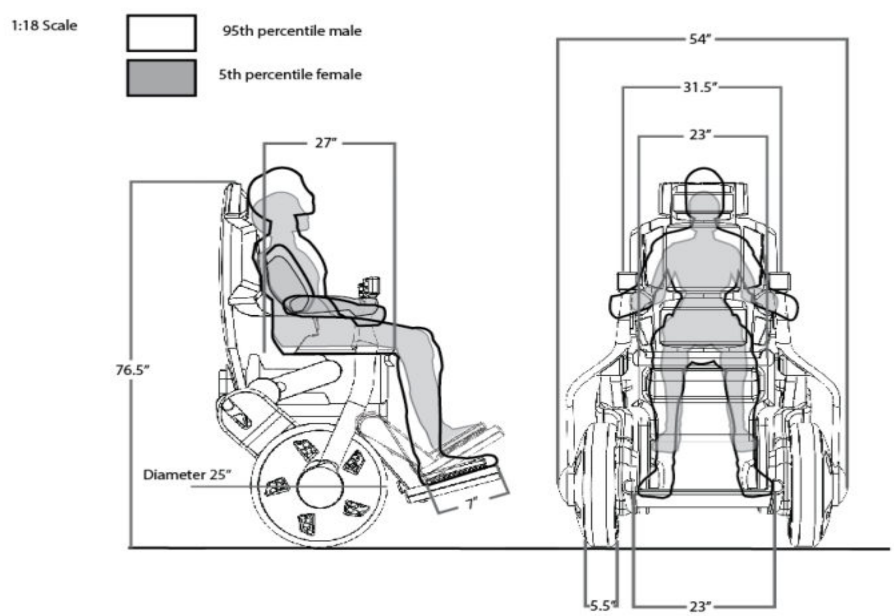


Figure 72

The controls are designed to be ergonomic by being placed in a neutral position for the users' arms, and all controls are electrically assisted to aid the user in the push/pull motions. Lastly, the footrest is highly adjustable to make sure the user is comfortable and as blood flowing to their legs at all times.

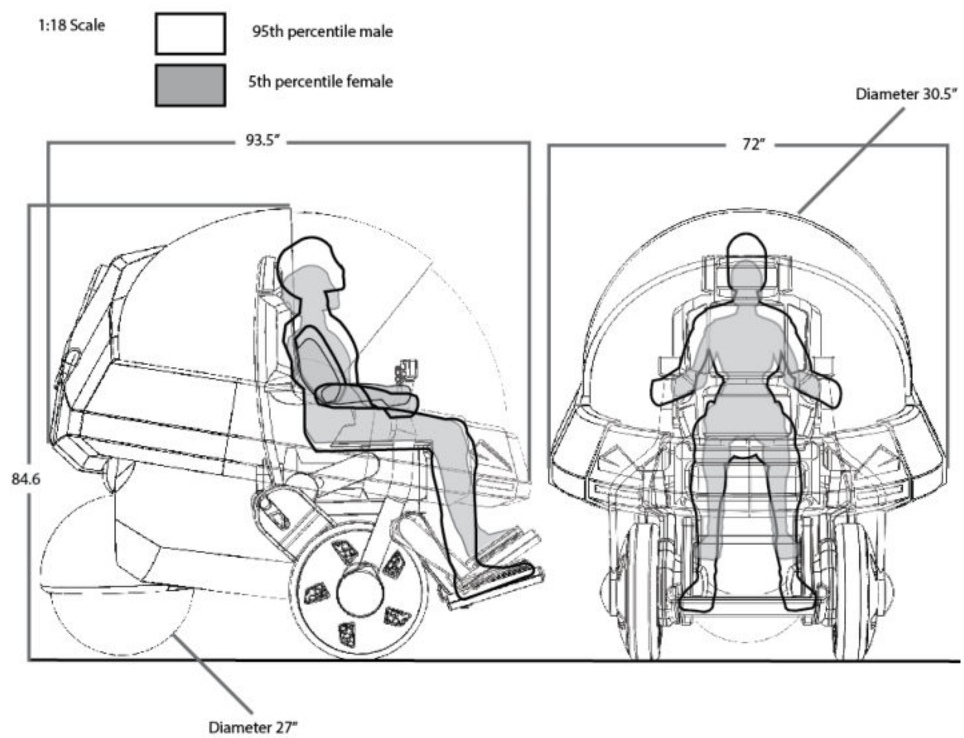


Figure 73

5.2.2 Materials, Processes and Technology

Materials

Beginning with the self-balancing wheelchair, the main shell of the body will use reinforced composite panels. This is to ensure that the wheelchair is not too heavy, thus improving the overall dynamics and efficiency of the vehicle. These composite panels will be secured to an aluminum frame that provides rigidity and surrounds the batteries. Components that the user interacts with include seat cushions, armrests, push/pull control arms, and hand controls. Seat cushions on the self-balancing wheelchair are finished with recycled fabric materials that are soft, and less slippery than leather or faux-leather materials. The control arms are fabricated from molded PLA plastic, which is starch-based and biodegradable, unlike existing petroleum-based plastics. The buttons on the hand controls are fabricated of the same PLA plastic, as it is lightweight and eco-friendly. All of the PLA-plastic used can be painted to describe the functions, as well as fit into the overall design theme of PIVOT. The reinforced composite panels used on the body will also be painted orange to ensure the chair is visible at all times.

Robotic functions of the chair, such as the self-balancing legs are intended to be constructed of steel because they are under the most stress on a daily basis. These components must remain rigid over long periods of time, and therefore require the most robust materials. Attached to the robotic legs are lithium-ion batteries that are housed in PLA-plastic housings to protect them from weather and dents. Lastly, the portion of the chair that meets the ground is the tires. These tires are airless and use a reinforced rubber honeycomb structure to maintain rigidity.

The outdoor-commuter pod that the self-balancing wheelchair connects into is constructed similarly to the wheelchair. Reinforced composite panels are secured to an aluminum frame that provides rigidity, as well as crash protection to the users and batteries. Other components of the pod are the folding upper canopy and the front crash-protection bar that surround the user when they enter the vehicle. The canopy is constructed of starch-based polypropylene that is crack-resistant and UV-resistant. The reason for this material is because it is clear like glass, but more lightweight. To secure the canopy in place and add front-crash safety, an aluminum structure emerges from within the pod and wraps around the front.

Around the rear of the pod, one can see a large spherical tire, rear brake light, and amber turn signals. The spherical tires use a similar airless technology that the front tires do on the self-balancing wheelchair. This is to ensure that the user is never left with a flat tire on the side of the road, especially since they are differently abled. The rear brake light and turn-signal housings are manufactured of starch-based plastics that are clear, then tinted red or amber colored.

Manufacturing

PIVOT is intended to be as eco-friendly and ethical as possible to separate itself from existing solutions. The manufacturing process aims to be based in North America because working conditions are heavily monitored in first-world countries. This ensures worker safety and fair pay. When dealing with electric vehicles, many toxic materials are required to be handled and assembled, and worker safety is of the utmost importance during these processes.

As mentioned in the materials above, the body panels of PIVOT are constructed of reinforced composite materials. These panels are shaped in molds and cured using UV light. These panels can then be painted to any color the user prefers. Providing structure to these body panels is an aluminum frame that consists of multiple die-cast pieces that are welded together to create a solid piece. This frame has many locating pieces for the composite body panels to snap into. Around the front of the pod is the starch-based polypropylene canopy pieces, which are simply created using injection molding techniques. Additionally, the front crash protection bar that extends and recedes around the user is created using multiple pieces of extruded aluminum that slide into one another. These aluminum extrusions are hollow, allowing for computers, wiring, and lighting to be housed within.

All components of PIVOT that are constructed using PLA starch-based plastic, such as the light housings, rims, and control arms of the self-balancing wheelchair are created using the injection molding technique. This ensures that the pieces are not only rigid but repeatable over time as more vehicles are produced. This technique also allows for the plastic to be hollow, thus creating room for motors and wiring to be hidden inside. This protects all the components from moisture and debris while also creating a clean aesthetic.

5.2.3 Design Implementation

The following table is a breakdown of materials and an estimated cost for each part based on industry standards. The table is broken into two sections to separate the chair and pod into two categories. An overall estimated cost is also included at the end that combines the two into an overall package as it would be sold to the end-user.

Self Balancing Wheelchair			
Component Name	**Material**	**Manufacturing Process**	**Cost Estimate USD**
Large Left Motor	Lithium Ion	Sourced from existing manufacturer	2000
Large Right Motor	Lithium Ion	Sourced from existing manufacturer	2000
Chair Back	Reinforced Composite	UV-curing pultrusion	600
Cushions	Recycled Cotton	Robotic upholstering	10
Footrest Arm Left	Reinforced Composite	UV-curing pultrusion	60
Footrest Arm Right	Reinforced Composite	UV-curing pultrusion	60
Footrest Middle	Reinforced Composite	UV-curing pultrusion	80
Footrest Cap Left	PLA Starch Plastic	Injection Molding	40
Footrest Cap Right	PLA Starch Plastic	Injection Molding	40
Control Arm Left	PLA Starch Plastic	Injection Molding	240
Control Arm Right	PLA Starch Plastic	Injection Molding	240
Left Headlight	PLA Starch Plastic	Injection Molding	20
Right Headlight	PLA Starch Plastic	Injection Molding	20
Left Rim	PLA Starch Plastic	Injection Molding	100
Right Rim	PLA Starch Plastic	Injection Molding	100
Small Motor Left	Lithium Ion	Sourced from existing manufacturer	1000
Small Motor Right	Lithium Ion	Sourced from existing manufacturer	1000
Left Tire	Reinforced Rubber	Injection Molding	750
Right Tire	Reinforced Rubber	Injection Molding	750
Suspension Left	Steel	Injection Molding	400
Suspension Right	Steel	Injection Molding	400
Finishing Cap Left	PLA Starch Plastic	Injection Molding	20
Finishing Cap Right	PLA Starch Plastic	Injection Molding	20
Frame	Aluminium	Injection Molding	4000
TOTAL			13950

Urban Commuter Pod			
Component Name	**Material**	**Manufacturing Process**	**Cost Estimate USD**
Battery Hub	Reinforced Composite	UV-curing pultrusion	1000
Canopy	Reinforced Composite	UV-curing pultrusion	1500
Front Bumper	Aluminium	Extrusion	2000
Powerwheel	Reinforced Rubber	Injection Molding	1750
Rear Spine	Reinforced Composite	UV-curing pultrusion	2750
Upper Battery	Lithium Ion	Sourced from existing manufacturer	5000
Frame	Aluminium	Injection Molding	4000
Total			18000

Cost of Wheelchair + Pod	31950

Table 9

The breakdown of cost and materials above is an estimated cost of each part that makes up the PIVOT project. This estimate does not include the cost of staffing and labor, nor does it incorporate the cost of facilities and machinery. Costs of testing, permits, and certifications are also unknown at this time. As these emerging technologies continue to advance, costs are expected to go down. This is because materials and manufacturing of these technologies should become more common and streamlined.

5.3 Final CAD Rendering

Figure 74

Figure 75

Figure 76

Figure 77

Figure 78

5.4 Physical Model

Figure 79

Figure 80

Figure 81

Figure 82

Figure 83

Figure 84

5.5 Technical Drawings

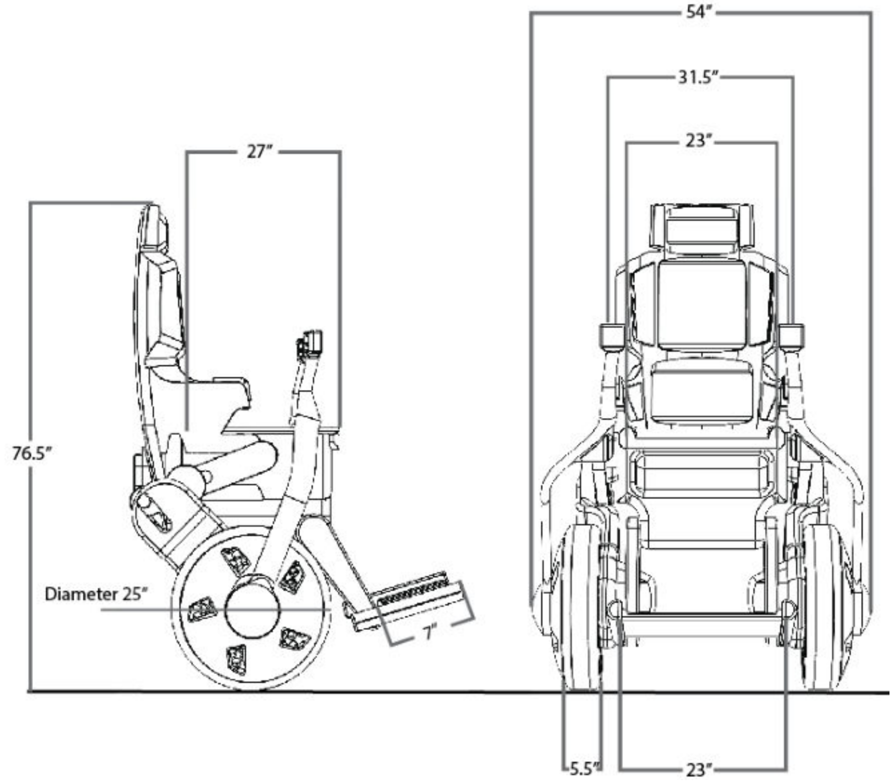


Figure 85

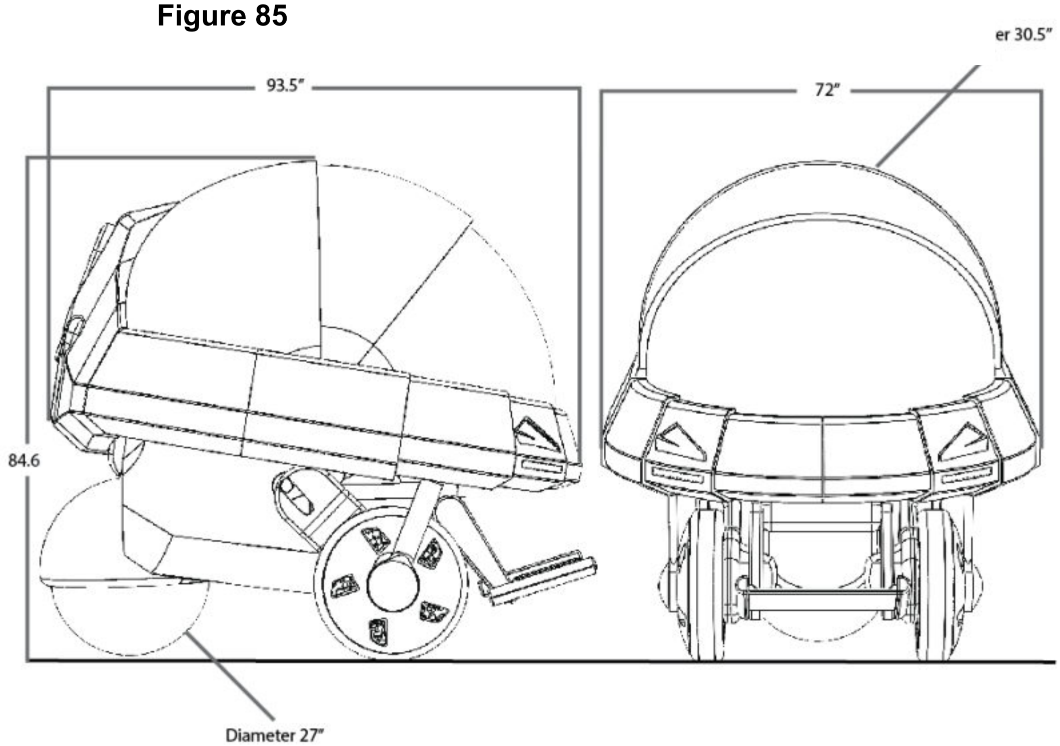


Figure 86

5.6 Sustainability

PIVOT is designed from the ground up to be a sustainable urban vehicle for wheelchair users. It achieves this by being electric-powered, small in size, and constructed with eco-friendly materials. It is no secret that the next generation of urban vehicles will aim to reduce congestion and pollution, and wheelchair users should be considered when designing smaller, more efficient vehicles.

Lithium-ion batteries emit absolutely no carbon emissions. This is an improvement over the existing solutions for wheelchair users because, for the most part, current vehicles emit carbon into the atmosphere. Even if the user of a wheelchair takes the subway to get to their destination, it is still an issue when trying to complete the last mile of their trip. These batteries are also convenient for the user because they can charge at home instead of wasting energy trying to get to a gas station. After the trip is completed, the self-balancing wheelchair is capable of maneuvering indoor areas. Electric power is even more important in this situation because the wheelchair must comply with noise regulations and indoor emissions regulations. Silent operation and zero emissions help keep the public comfortable and safe while commuting alongside PIVOT.

A small footprint is another way to make PIVOT more sustainable. As density increases, space becomes more valuable. PIVOT has a very small footprint, being 12.6 inches shorter than a Smart Fortwo (15). This allows PIVOT to be more efficient in parking and more efficient on the road. By reducing density, we can fit more vehicles into existing spaces. In the end, traffic and parking issues are lessened which creates a more efficient urban environment.

Last, the materials used to construct PIVOT are as sustainable as possible, thus ensuring the vehicle’s environmental footprint is as small as possible. Emerging technologies allow for the use of PLA plastic that is starch-based instead of the conventional petroleum-based equivalent, as well as reinforced composite panels that are more eco-friendly than existing metal panels.

Even the aluminum and steel that are used in the rigid components of PIVOT are designed to be made of recycled material. Aluminum can be made of recycled soda cans, and steel can be made of recycled vehicle parts. Overall, PIVOT is a sustainable solution from start to finish.

CHAPTER 6: Conclusion

PIVOT is an accessible vehicle designed for wheelchair users in urban environments. Current solutions for wheelchair-accessible vehicles often include ramps or lifts to enter the vehicle, and this is not practical due to the large footprint necessary to accommodate these systems. These methods of transportation also require a tremendous amount of planning to arrange pick-up and drop-off. PIVOT aims to be more practical, and more environmentally friendly than a conventional accessible vehicle by being electric powered, smaller in size, and manufactured using eco-friendly materials. All of these challenges were achieved without the need for a ramp or lift, thus reducing the time, energy, and planning necessary to complete a journey. This ease of travel will ultimately reduce the feelings of isolation that may occur in the differently-abled.

Figure 87

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Appendix A – Discovery

The objective/goal of this report is to become familiar with the Humber Library Search Engine, Library Databases, and other search engines. This will be applied to my thesis topic, and I will use these resources to begin gathering information. The area of focus will be personal transportation for adults with mobility disabilities.

Problem Statement (search topic)

Thesis topic: Improving mobility for the physically challenged in urban areas

Background: People with mobility disabilities are a group who does not have many options in the transportation industry. Future technologies such as autonomous driving and electric powertrains will allow automotive manufacturers to eliminate the gas and brake pedals from their vehicles. Therefore, someone who uses a wheelchair or other mobility aids will be able to operate a vehicle on their own. When researching concept cars that represent a manufacturers vision for the future, it is common to see autonomous technology at the forefront. However, I could not find one concept that could be entered by wheelchairs.

Needs statement: Adults with mobility issues need to be able to access personal transportation without scheduling an appointment ahead of time.

How is this need being addressed currently? Current options for wheelchair transit include TTC wheel-trans, private charters, and wheelchair-accessible vans. The problem with these options is that they can be very expensive or too inconvenient. An adult who uses a wheelchair cannot simply drive a personal vehicle to the grocery store or to work. If a physically challenged person were to purchase a vehicle with their own money, it would have to be a converted minivan that still requires another person to be the driver. Automotive manufacturers are investing heavily into autonomous technology as the future of mobility for all, meaning a driver would no longer be necessary.

Key Article 1

Method

A key article related to my topic was selected after a search using related terms. The Abstract, Introduction, and Conclusion have been copied from the source and highlighted.

Search Engine: Humber Library (Library.Humber.ca)

Key Words Used: “Wheelchair mobility in urban areas”

Findings

Citation

Velho, R., Holloway, C., Symonds, A., & Balmer, B. (2016). The effect of transport accessibility on the social inclusion of wheelchair users: A mixed method analysis. *Social Inclusion, 4*(3) doi:http://dx.doi.org.ezproxy.humber.ca/10.17645/si.v4i3.484

Key Content

Abstract

In recent years the accessibility of London buses has improved with the introduction of ramps and wheelchair priority areas. These advances are meant to remove physical barriers to entering the bus, but new conflicts have arisen particularly over the physical space aboard. We aimed to research the barriers faced by wheelchair users in public transport using a mixed methods approach to establish the breadth of issues faced by wheelchair users. To this end we quantified the push-force used alight a bus and a study to understand the coping mechanisms used by people to propel up a ramp. This quantitative approach found push forces which resulted in a load of 2 to 3 times body weight being transferred through people’s shoulders, forces which can be directly linked to shoulder injury. This could disable the user further, preventing them from being able to push their wheelchair. Alongside the quantitative study, we conducted qualitative research comprising of a number of in-depth interviews with wheelchair users about the barriers they face in public transport. Our main claim, highlighted through this interdisciplinary collaboration, is that proposed ‘solutions’ to accessibility, such as ramps, often generate problems of their own. These barriers can affect the life of wheelchair users, impacting on their confidence and causing social isolation. These can be long-term in nature or immediate.

Introduction

“If I were to ask you to describe transport accessibility for wheelchair users in London as it is today with three words, what are the three words you would choose?” “Well-intentioned. Inadequate. Uninspiring.” (Peter) With three adjectives, Peter painted a less than ideal image of London’s public transport from his perspective. A 25-year-old lawyer who works and lives in Central London, he carefully chose where to live in the European capital to ensure an easier commute, requiring only a short underground journey on the famous Tube network. His is one of several stories and ways of talking about transport and its impact on people’s lives, particularly the influence that transport (in)accessibility might have on wheelchair users’ social inclusion. In this article, we want to consider transport and inclusion with wheelchair users’ accessibility to the network as the primary focus by using two, quite different, disciplinary approaches—sociology and engineering. The aim is to highlight how both approaches demonstrate, in different ways, how solutions proposed to improve accessibility may also generate future problems for wheelchair users. In 2005, the main transport authority in London, Transport for London, introduced low-floor buses with boarding ramps for wheelchair users. These buses would eliminate some obvious physical obstacles (compared to the previous model of buses, the Routemaster, which had a step) and permit wheelchair users to board and alight buses, ensuring their inclusion to one mode of the public transport network. However, as we will discuss below, this implementation was not the end of accessibility problems as wheelchair users can also face other issues. Indeed, with wheelchair users being able to physically use the bus, other conflicts began to appear generated by these improvements. This research was initially developed as a pilot study in 2013 as a collaboration between the UCL departments of Civil, Environmental and Geomatic Engineering and of Science and Technology Studies. The intention was to think about accessibility from both perspectives, quantitative and qualitative, with the aim of seeing whether these two ostensibly incommensurable disciplines could inform each other and provide new insights into transport accessibility for wheelchair users. The aim of this article is to explore the initial results of this interdisciplinary collaboration. To begin, we will briefly describe the policies and regulations which frame transport accessibility in the UK and, more specifically, London. We will then address the question of accessibility with a mixed methods approach, developed below in two separate sections: the first offers a quantitative analysis from an engineering and biomechanics perspective. The second section takes on a qualitative approach, based on the field of Science and Technology Studies. In the last section we ask what new insights were acquired through the collaboration of engineers and social scientists, and discuss the rigidity of the transport system in London as it affects wheelchair passengers.

Conclusion

In this article we intended to think about accessibility through an interdisciplinary lens, using both an engineering and a sociological approach, and consider the new insights this collaboration might bring. Transport is an essential service to the population which ensures people’s inclusion in society as it provides the link between the private (the home) and the public (the museum, coffee shop, Parliament, etc.) spheres. In the case of our participants, we can see that issues around the accessibility of public transport can lead to anxiety and social isolation, but also to physical injury. The collaboration between disciplines helped to highlight that what can be framed as a solution to barriers in accessibility can also generate problems in itself, such as ramps becoming broken or straining wheelchair users’ bodies and causing harm. This is often due to the ‘addon’ nature of some of these fixes onto a system that has already been mostly stabilised in the past century. Despite STS and ANT theories telling us that these systems are more complicated, our interviewees described the issues they face as physical, spatial, or social which we suggest is due to their experiences being fragmented. For this reason, policy-making in transport, including the establishment of legislation, regulations and best-practice guides, should be developed in as plural a manner as possible where, rather than speaking in terms of 'solutions', ongoing conversations about improvements are held. The physical and spatial environment needs to be understood and people's abilities can be measured to provide better guidance. This should also be supplemented by the understanding that transport is an extremely large network which encompasses not only things, technologies and policies, but also a wide variety of people and social interactions. A plural approach to investigating the limits and weak points of public transport networks, including engineering, biomechanics, sociology, city planning, among others, can permit a wider range of solutions to be proposed.

Summary Statements

1. While improvements are being made for wheelchair accessible transportation, some of the changes are doing more harm than good

2. When going up a ramp, 2 to 3 times the users body weight is transferred through the users shoulders which could result in further injury.

3. Wheelchair users often have to choose where they live based on accessibility to wheelchair friendly transit.

4. Barriers caused my injury, anxiety, or fear can cause social isolation of wheelchair users, either short-term or long-term

5. Transport is an essential service to the population, and ensures people's inclusion in society as the link between the private and the public spheres.

Key Article 2

Method

A key article related to my topic was selected after a search using related terms. The Abstract, Introduction, and Conclusion have been copied from the source and highlighted.

Search Engine: Google Scholar through Humber proxy (https://scholar-google-ca.ezproxy.humber.ca/)

Key Words: "Wheelchair mobility in urban environment"

Findings

Citation

Yokozuka, M., Suzuki, Y., Hashimoto, N., & Matsumoto, O. (2012, October). Robotic wheelchair with autonomous traveling capability for transportation assistance in an urban environment. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 2234-2241). IEEE.

Abstract

To realize a new type of personal vehicle for elderly people while contributing to a low-carbon traffic society, we have been developing a robotic wheelchair with autonomous traveling and obstacle avoidance in an urban environment. In this paper, we primarily discuss two kinds of key technologies, long-distance autonomous travel in an outdoor environment and obstacle avoidance in a human-shared environment. For the localization and navigation methods, we propose sub-map dividing and realignment with FastSLAM, which enables generation of large-scale 3D voxel maps by the sampling based SLAM method. For the planning and obstacle avoidance methods, we propose motion control by a combination of the global/local A* algorithm and the dynamic window approach. To confirm the effectiveness of our proposed methods, the results of demonstration experiments using our robotic wheelchair `Marcus' in the Tsukuba Robot Zone are also reported.

Introduction

Transportation such as automobiles, ships, and airplanes emit 20% of the total greenhouse gas in Japan. Therefore, automobile companies have recently been developing hybrid cars, electric cars, etc., in order to contribute to a low-carbon traffic society. In addition, local governments in Japan have been studying the concept of a compact city aimed at a sustainable society, in which many functions necessary for life are close. In this concept, everyday facilities are within walking distance, public transportation system is utilized for long-distance transportation, and personal vehicles are uti1ized for short-distance transportation, all of which contribute to environmental conservation and a sustainable society.

Another benefit of a compact city is the reduction of the number of traffic accidents, especially by Japan's increasing population of aged drivers. One of the personal vehicles for aged people is an electric wheelchair. In our research, we are developing a robotic wheelchair with autonomous traveling for convenience and obstacle avoidance for safety. As the wheelchair hardware, we utilized a motorized wheelchair with motor driving units attached to the right and left wheels, because this design leads to a wheelchair that is compact, lightweight, and easy to use.

To enable vehicles to have autonomous traveling capability in an urban environment, many related research studies have been performed. Many kinds of research and development have investigated autonomous automobile travel based on 3D light detection and ranging (LIDAR), vision sensors, and obstacle avoidance. For small types of personal mobility, a 3D map generation method for outdoor autonomous travel using a two-wheeled inverted pendulum type of vehicle has been proposed.

Moreover, for elderly and disabled people, related research studies on autonomous robotic wheelchairs in an indoor environment have been performed.

In this paper, first we describe our developed robotic wheelchair and its system components and operation. Next, we describe the Tsukuba Robot Zone, which is a real and public environment for demonstration experiments. Then, we discuss two kinds of key technologies, long-distance autonomous travel in an urban environment and obstacle avoidance in a human-shared environment, and show the experimental results of operating our robotic wheelchair in the Tsukuba Robot Zone. Finally, we conclude our paper and discuss future work.

Conclusion

We have described our robotic wheelchair Marcus and two key technologies for autonomous traveling and obstacle avoidance. The first key technology is *sub-map dividing and realignment FastSLAM* that enables generation of a large-scale 3D voxel map by a sampling based SLAM method. The experimental results show that our SLAM method has the potential to generate a large-scale voxel map, which is difficult for FastSLAM to generate due to the huge memory usage. The second key technology is *motion control by a combination of the global/local A* algorithm and the dynamic window approach*. By using these two key-technologies, our robotic wheelchair Marcus had the capability for long-distance autonomous traveling in an urban environment and obstacle avoidance in a human-shared environment.

Summary Statements

1. A new type of vehicle is necessary for the elderly/disabled to contribute to a low-carbon society.

2. New technologies are being developed to allow these vehicles to be autonomous.

3. Both long-distance and short-distance vehicles need to be considered when developing a low-carbon society.

4. Another benefit of autonomy is reducing traffic accidents, especially with the aging population.

5. An autonomous wheelchair is currently being studied, named Marcus

Appendix B – Contextual Research (User)

How may we improve transportation for the physically challenged in urban areas?

Design Research Focus
- To reduce isolation by increasing supervision-free transportation
- Reduce stress on the body by automating transportation

Goals for User Observation
- Observe how user interacts with their vehicle
- Observe pain points of current solutions
- See what works for users so they can be included

USER

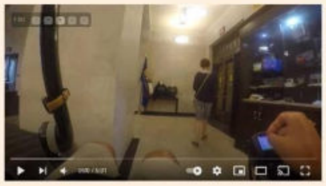
Name: Shane
Age: 28
Residence: Toronto, Ontario
Education: University Graduate
Occupation: Web design
Marital status: Single

Needs
- Easy transportation to work
- Social time with friends
- Errands for food and supplies
- Work to pay rent in the city

Wants
- To be able to go out without planning well ahead of time
- To avoid public transport during rush hour
- The freedom to explore the city on his own

USER OBSERVATION BY VIDEO

"WHEELCHAIR USER GETTING ON & OFF TRAIN", AUG 4TH 2015, HTTPS://WWW.YOUTUBE.COM/WATCH?V=4GADCCAQETS



Preparation

User approaches the door to enter the station

Step 1

User navigates union station, which mostly has long ramps and flat floors. This benefits the user as he does not need assistance to clear these obstacles.

Step 2

When the user reaches a portion of the station that has stairs, a worker assists him with an elevator that takes him down to the train platform

USER OBSERVATION BY VIDEO

"WHEELCHAIR USER GETTING ON & OFF TRAIN", AUG 4TH 2015, HTTPS://WWW.YOUTUBE.COM/WATCH?V=4GADCCAQETS

Step 3

User makes it to the platform and approaches the train. There is construction going on which narrows the path and results in user going close to tracks.

Step 4

To enter the train, a worker must push loading machine up to the train. This takes time and puts strain on the worker.

Step 5

User is now on the train. A worker assists the user by lifting the table and putting straps on the wheelchair to secure the user in place.

USER OBSERVATION BY VIDEO

"WHEELCHAIR USER GETTING ON & OFF TRAIN", AUG 4TH 2015, HTTPS://WWW.YOUTUBE.COM/WATCH?V=4GADCCAQETS

Step 6

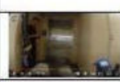
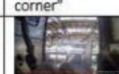
Exiting the train proves difficult as the path is very narrow. A worker meets the user with the lift mechanism ready to help the user exit the train.

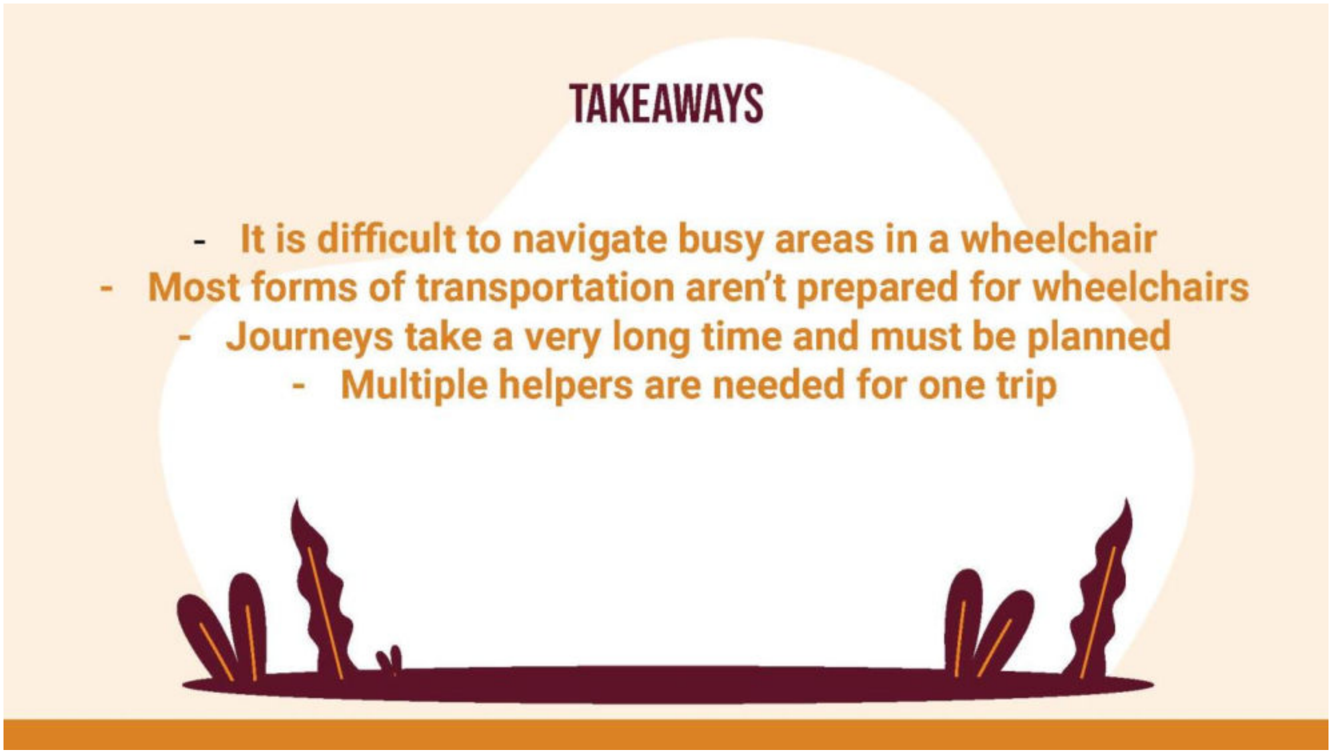
Step 7

User heads for the exit. Once again the path is narrow which pushes him close to the train tracks

Step 8

User approaches elevator to leave the platform and enter the station. This is where the journey ends

	Preparation	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8
User Goals	Enter station	Navigate ramps	Enter elevator	Navigate Platform	Enter train	Get secured for travel	Exit train	Navigate platform	Enter elevator
Actions	-Navigate around people - Open door - Go through door	- Approach ramp - Navigate around people - Go down ramp	- Worker presses button - Worker helps user enter - Worker rides with user	- Go around construction - Look out for people - Keep an eye on tracks	- Worker pushes lift up to train - User waits - Enter lift - Enter train	- User waits - Worker lifts table - Worker secures user to straps	- Navigate narrow isles - Enter the lift machine - Ride down off the train	- Go around construction - Look out for people - Keep an eye on tracks	- Worker presses button - Worker helps user enter - Worker rides with user
Thoughts	"Hopefully it's wide enough and not busy"	"I wonder if I'm blocking anyone"	"I wish I could do this without assistance"	"I need to go slowly to avoid the tracks"	"Good thing I'm not in a hurry"	"This worker is really in my personal space"	"This is really hard to get around the corner"	"Once again, I am close to the tracks"	"I'm glad that I made it safely"
Photos									
Experience									
Problems	Door is difficult to open	People are walking around	Takes a long time and is awkward	Construction pushes user near tracks	Takes a long time and is complicated	Worker has to invade personal space	Path is too narrow, is difficult to navigate	Path is too narrow, pushes user near tracks	Is time consuming


TAKEAWAYS
- It is difficult to navigate busy areas in a wheelchair
- Most forms of transportation aren't prepared for wheelchairs
- Journeys take a very long time and must be planned
- Multiple helpers are needed for one trip

Appendix C – Field Research (Product)

Product 1- EasyFold PRO 2.0

https://easyfold.ca/easyfold-bundle-sale/?utm_source=google&utm_medium=shopping&utm_campaign=easyfold_shopping&gclid=CjwKCAjwzOqKBhAWEiwArQGwaIVuL96J69M_EsT0dym3nrV5Us5WRzFIUWMiagCGP43s1_SiC_y5phoCm0AQAvD_BwE

Search: Wheelchairs

Figure 9: https://easyfold.ca/easyfold-bundle-sale/?utm_source=google&utm_medium=shopping&utm_campaign=easyfold_shopping&gclid=CjwKCAjwzOqKBhAWEiwArQGwaIVuL96J69M_EsT0dym3nrV5Us5WRzFIUWMiagCGP43s1_SiC_y5phoCm0AQAvD_BwE

Description: This lightweight powerchair is your ideal companion for every day mobility and travel. It easily folds down to a compact size so it can be stored at your home or transported in the back of a vehicle without the use of a ramp.

Like many other modern powerchairs, the EasyFold PRO 2.0 is driven using a joystick controller that can be easily mounted on either side of the power chair. It also equipped with a flip back armrest for easier transfers and access.

Composed of a very durable lightweight aluminum alloy, with an 8" front wheels, 12.5" rear wheels and two 250 Watt Brushless HUB motors to power them. You will be amazed at how effortless it is to quickly fold this chair to a compact size. Unfolding is just as easy! The EasyFold Pro 2.0 comes with two removable quick connect LifePO4 Lithium-ion, 24V 6aH batteries and a maximum speed of 6 km/h. Your purchase includes everything you need to use it! — Included in each order will be two 24 V 6 Ah Battery and of course the Joystick

Specs:

Cost: $5,552.88 CAD

Speed: 6KM/H

Range: 24 KM

Weight: 59 lbs

Capacity: 1 person, 369 lbs

Slope capacity: 20% slope (12deg)

Material: Aluminium Alloy and nylon fabric

Ground clearance: 5"

Dimensions: 38"L 25.5"W 37"H

Pros:

Foldable, high weight capacity, left or right side movement controls, compact.

Cons: Low range, no weather protection, high cost

Product 2- Bariatric Heavy Duty Transport Wheelchair

https://www.vitalmobility.ca/Bariatric-Steel-Transport-Chair.php

Search: Wheelchairs

Figure 2:

https://www.vitalmobility.ca/Bariatric-Steel-Transport-Chair.php

Description:

The Bariatric Steel Transport Chair offers variety as it is available in in 20" seat width with red or blue frame, as well as 22" seat width which comes in red, blue or silver vein frame finish.

It features dual, reinforced steel cross braces.

Supports individuals up to 450 lbs with it's reinforced steel frame that provides added support.

Includes heavy-duty, nylon reinforced upholstery with a back carry pouch.

Also features removable, reversible desk length arms as well as adjustable leg support and 12" rear flat free wheels

Specs:

	20" Seat Width	22" Seat Width
Overall Width (open)	24.5"	26.5"
Overall Width (closed)	9"	11.5"
Overall Height	37"	35.5"
Seat-to-Floor Height	20.5"	20.5"
Back Height	16"	16"
Seat Width	20"	22"
Seat Depth	18"	18"
Overall Length w/ riggings	38"	38"
Product Weight	45 lbs	49 lbs
Weight Capacity	450 lbs	450 lbs

Pros:

Offers multiple seat widths, multiple colours, supports up to 4502 lbs, removable arms, flat-free wheels, lower cost ($549)

Cons:

Arm-powered, no weather protection, no electrical assist, difficult to store

Product 3- Viper Plus Reclining Wheelchair

https://www.vitalmobility.ca/Viper-Plus-Full-Reclining.php

Search: Wheelchairs

Figure 3: https://www.vitalmobility.ca/Viper-Plus-Full-Reclining.php

Description:

Built-in seat rail extension and extendable upholstery easily adjusts seat depth from 16" or 18"

Attendant wheel locks in a convenient and easily accessible location

Spreader bar acts as a back stabilizer and a convenient push handle for the attendant

Offset rear wheel position adds additional stability and equally distributes the patient's weight while in the various reclining positions

Hydraulic reclining mechanism allows for adjustments up to 180°

Durable, flame-retardant nylon upholstery resists mildew and bacteria

Carbon steel frame with double-coated chrome for an attractive, chip-proof, maintainable finish

Composite Mag-style wheels are lightweight and maintenance free Also features 8" front casters

Nylon, padded armrests provide added patient comfort, and feature the flip-back style for easy transfers

Precision sealed wheel bearings in front and rear ensure long-lasting performance and reliability

Standard dual axle provides easy transition of seat-to-floor height from adult to hemi-level

Front caster forks are adjustable in three positions

Comes standard with swing-away elevating leg rests

Composite foot plates are durable and lightweight

Urethane rear tires and casters offer superior performance, smoother ride and are lightweight

Specs: Price: $1,459

	16" Seat	18" Seat	20" Seat
Weight Capacity:	300 lbs	300 lbs	300 lbs
Weight:	47 lbs	49 lbs	51 lbs
Seat Width:	16"	18"	20"
Seat Depth:	16"-18"	16"-18"	16"-18"
Seat-to-Floor Height:	17.5"/19.5"	17.5"/19.5"	17.5"/19.5"
Overall Dimensions Open: (w/riggings)	24" x 42"	26.5" x 42"	28" x 42"
Overall Dimensions Closed: (w/riggings)	12.5" x 42"	12.5" x 42"	12.5" x 42"
Footrests:	Elevating	Elevating	Elevating
Castor Size:	8"	8"	8"
Carton Shipping Weight:	53 lbs	55 lbs	57 lbs

Cons: Arm powered, higher cost, large heavy frame, difficult to maneuver and store, no weather protection

Product 4- Enhance Mobility Transformer Scooter

https://www.1800wheelchair.ca/product/enhance-mobility-transformer-scooter/

Search: Power Scooters

Figure 4: https://www.1800wheelchair.ca/product/enhance-mobility-transformer-scooter/

Description:

This easy to use, ultra-portable electric scooter offers the ultimate in convenience. Offering remote control operation and manual if required. The Transformer has a 300lb weight capacity and comes standard with a lightweight Lithium battery (13.5 Miles on a single charge).

The Transformer folds into a very compact and easy to manage unit. It easily fits into the back of the smallest hatchback. It is also airline friendly and fully compliant and within regulations for Lithium Ion dry cell battery

Specs:

Price: $5,251 CAD

Weight Capacity	**300 lbs.**
Product Weight	**53 lbs.**
Seat Width	**17"**
Seat-to-Floor Height	**22"**
Overall Width	**18.1"**
Overall Length	**36.9"**
Frame Color	**Black - Yellow**
Frame Type	**Foldable**
Front Wheel Size	**6"**
Rear Wheel Size	**7"**
Wheel Type	**4-Wheel**
Turning Radius	**55"**
Max Climbing Angle	**15 degrees**
Max Speed	**3.7 mph**
Driving Range	**13.5 Miles**
Warranty on Frame	**Two Year Limited**
Warranty on Electronics	**Two Year Limited**

Cons: Price, size, maneuverability, no weather protection or outdoor use, difficult to access

Product 5- Green Transformer Q Runner Scooter

https://www.electricwheelchairsusa.com/products/green-transporter-q-runner-electric-transport-scooter?variant=15155407552547

Search: Two person electric scooter

Figure 5: https://www.electricwheelchairsusa.com/products/green-transporter-q-runner-electric-transport-scooter?variant=15155407552547

Description:

This mobility scooter is definitely not like your average scooter. This one comes with an enclosure, has a backup camera, and also sports a multimedia player. If you care for a ride out and you don't want to be bothered by the sun, then this is your perfect ride. It has a battery range of 25-35 miles before you need to recharge the battery, and runs at a top speed of 18mph. Not only does it have a weight capacity of 550 lbs, but it has a front and rear seat. To allow a draft to come in, it has two roll down side windows, a rear window and a sunroof. In order to view your mileage and such, it comes completely fitted with a digital dashboard that displays mileage, speed, and battery. Using the multi-media player you can pair your Bluetooth or sync your music via the usb port. It has a full lighting system with tail lights, turn signals, and dual LED headlights. It comes complete with an integral suspension system for a smoother ride.

Specs:

Price: $9,995 USD

Size	90" x 46" x 63" (L*W*H)
Motor power	1200W
Battery	60V 45AH Lead Acid
Max speed	18 mph
Wheel base	1580mm
Tire	125/65-12
Tricycle weight	600 lbs
Brake system	Front and rear disc brake
Range:	25-35 miles
Max Load:	550 lbs
LCD Instrument Panel	Yes
Back Up Camera	Yes
Roll Down Front Windows	Yes
Heater	Yes
Radio	USB/Bluetooth/AUX
Rear Bench Seat:	34" x 15"
Ground Clearance:	6.5"
Bench Height from floor:	16"
Between seat and bench:	12"
Max Incline:	25 degrees
Suspension:	Integral Damping
Brake:	Disc

Cons: Low range, lack of luxury features, not suitable for roads and highways, difficult to access

Product 6- Trickaroo Boomer X

https://www.trikaroo.com/product/trikaroo-boomer-x/63

Search: Two person electric scooter

Figure 6:

https://www.trikaroo.com/product/trikaroo-boomer-x/63

Description:

The Trikaroo Boomer X is the first expandable Two Seater MicroMobility Electric Passenger Vehicle of its kind, with just a squeeze of the handle, it transforms from a single seat electric vehicle to a two seater. The Trikaroo Boomer X can reach top speed of 15 mph with a load capacity of 600 lbs. This scooter is extremely stable with its over sized balloon tires and a 500 watt dual-drive motor which turns both rear wheels making traveling through grass and dirt easy. The Boomer X comes standard with headlights, taillights, turn signals, horn, USBport, alarm system with key-less remote and motorcycle style hydraulic brakes that stop on a dime. The Trikaroo Boomer X is both street legal and A.D.A. compliant fitting through most standard doorways. You are sure to turn heads when you hop on a Trikaroo Boomer X driving through your community

Specs:

Price: $4,295 USD

Seats two adults
Up to 40 miles per charge*
Goes up to 15 miles per hour*
Steel Construction
Front L.E.D. head light
Rear running lights
Front and Rear turn signals
Forward and Reverse switch
Horn
Governor to reduce speed
Front Metal basket
Rear removable basket
Collapsible
Keyed ignition
Front and rear suspension
Size: 55L x 29W x 42H inches
Size extended: 82L x 29W x 42H inches

Cons: Low range, no weather protection, lack of luxury features, not suitable for roads and highways, difficult to access

Product 7- Toyota Sienna Power Fold Out

https://www.humberviewmobility.com/vehicle/2020-toyota-sienna-braun-power-fold-out/

Search: Wheelchair accessible van

Description:

The Toyota Sienna with a Braunability Power XT Bifolding Wheelchair Accessible Vehicle Conversion features a 56.5” passenger door opening with removable front row seating. At the touch of a button the passenger sliding door opens and the fold out ramp lowers to allow its user entry into the vehicle. The integrated kneeling feature also lowers the vehicle reducing the angle of the ramp making it easier for a wheelchair user to enter in and out of the van. With both LE and XLE models in stock, we have multiple units available and ready for the road.

Figure 7: https://www.humberviewmobility.com/vehicle/2020-toyota-sienna-braun-power-fold-out/

Specs:

Price: approx. $50,000 CAD
Make: Toyota
Model: Sienna
Year: 2020
Inventory: Available
Colour: Multiple available
Removable front row seating
1000lbs ramp weight capacity
5” passenger sliding door entry height
Flip down foot rest for third row passengers

Cons: Price, full-time driver necessary

Product 8- TTC Wheeltrans

https://www.ttc.ca/WheelTrans/About_Wheel-Trans/index.jsp

Search: Wheelchair accessible transportation Canada

Description:

TTC Wheel-Trans provides a safe and reliable accessible transportation option for persons with disabilities to travel with freedom and dignity. This includes Wheel-Trans trips that connect customers to a subway station or bus stop. Wheel-Trans vehicles include accessible buses, contracted accessible taxi minivans and sedan taxis. Currently, there are more than 42,000 registered customers who use our service and we provide over 4 million door-to-door trips each year in the City of the Toronto. Service is provided anywhere within the City of Toronto under regular TTC fare structure. Wheel-Trans is a shared ride, public transportation service.

Figure 8: https://www.ttc.ca/WheelTrans/About_Wheel-Trans/index.jsp

Specs:

Price: Free

24 hours, 7 days a week

Trips must be scheduled ahead of time, preferably 7 days

Same day trips must be scheduled 4 hours ahead of time

Must schedule departure time as well

Will receive confirmation ahead of time

Non-dependants must pay fare

Driver will escort from vehicle to door of destination

Busses cannot enter residential driveways

Must have space for ramp, cleared of hazards

No animals allowed

Cons: Must be scheduled well ahead of time, limit to number of passengers, limit storage, weather dependant

Appendix D – Results Analysis

Curtis Dougan 0:06
Hi, is this Karen? Yes. Hi, Karen. It's Curtis Dougan. How are you?

Karen Medd 0:12
I'm good. How are you?

Curtis Dougan 0:13
I'm doing very well. Thanks. So yeah, just want to say, I really appreciate you taking the time to talk to me. It's it's awesome. How can we? Yeah, I love so a few questions prepared. I'll be sure not to take up too much your time or anything. Okay. Yeah. So yes. Yes to start. Just how long? Have you been using a wheelchair for

Karen Medd 0:44
just over 10 years?

Curtis Dougan 0:45
10 years. Okay. And is it a manual or a powered wheelchair?

Karen Medd 0:51
I have both but right now mostly I use the power chair.

Curtis Dougan 0:54
Okay. So um, do you live in a rural urban or suburban area? Suburban, okay. So, so you said before that you you operate a vehicle. So what what type of vehicle do you use to get around the city? Emily? Minivan?

Karen Medd 1:18 Yeah.
Toyota Sienna.

Curtis Dougan 1:21
Okay, and that's like a with the hand controls, I'm assuming. Yes. Yeah. Awesome. So how often would you drive the minivan? Kind of downtown Toronto and like dense urban areas?

Karen Medd 1:35
I know. I don't really go to downtown Toronto. It's more around new market and stuff. Yeah, so it's not as condensed as Toronto. Driveway Toronto.

Curtis Dougan 1:52
Yeah, so if you did have to go into the city, what method of transportation would you typically use to get down there? I like drive. Yeah, so you would drive down there? Yep. Awesome. So on this what do you find when you do drive around like what are what are the greatest obstacles you face while driving? Your minivan? parking? Parking Yeah.
Karen Medd 2:22

Yeah, like just worried. About is there going to be a spot where the ramp goes down where someone doesn't block me in? So when they come back to the car, will I be able to get into it or will someone is parked beside me? Yeah, that's the main concern.

Curtis Dougan 2:38
So it's the type of Van where you you enter through the rear.

Karen Medd 2:44
I know mine is on the side. Okay, so there's a ramp that comes down to the side door No, kind of. Okay. How difficult Do you find it is to get up and down that ramp? Oh, it's easy.

Curtis Dougan 3:00
Yeah, because the power wheelchair.

Karen Medd 3:04
Well, it's a power chair but it's also not a very steep ramp because when they modify the van they drop the floor. So they drop the floor of the van so it and then the van lowers itself when you have that option turned on so it lowers itself and you put the ramp so it's not a steep ramp whereas the old vehicle I had had a very steep ramp. And that was quite a bit more difficult. Oh yeah, like that. One. I think people in the manual chair would have a hard time getting up it. Yeah, cuz it was too steep for that.

Curtis Dougan 3:44
For sure. Yeah, no, definitely. And so my research I've done I've heard Yeah, people using manual wheelchairs. It can be quite hard on like their shoulders and they can actually injure those even further.

Karen Medd 3:59
Exactly.

Curtis Dougan 4:01
Yeah. Awesome. So I'm now kind of shifting to from the vehicle and then going from the vehicle to an indoor setting. How, how easy or difficult is that step? Like parking and exiting is one thing but then the journey to indoors.

Karen Medd 4:31
I don't find that difficult. I mean, it all depends where you're trying to go and whether it's accessible. Yeah, yeah. I don't tend to have a problem with it. But I think depending on whether you're paraplegic quadriplegic, you know how good your motor skills are, determines whether some people have more difficulty than others. Certainly, in a manual chair, getting around indoors is very easy. But obviously, it takes a lot more work to get from your car to a place. You know, it's harder on the shoulders. It's harder on your body.

Curtis Dougan 5:20
Yeah, yeah, I can imagine. So, once you once you find it like once you get

indoors, do you find it's difficult to maneuver around inside?

Karen Medd 5:36
Um I don't find it very difficult, but again, it really depends on your motor skills. You know, I have full use of my hands and arms. So when I like to think I'm a good driver, but certainly I mean, some of our walls have marks on them, you know, where you don't turn quite as tightly as you meant to go to taking the doorframe by mistake. So it's like I had one chair that was I forget which one whether it's we're driving or I think my old chair was easier to turn quarters than my new one. It took a bit more getting used to because it just turned differently. It wasn't as pipe turning but it had a lot of other features that needed a better chair. Okay, so it's going through door frames and doing tight turns in older houses that might have you know, narrower hallways and stuff that can be a little more challenging. But I mean, certainly like a mall or something that's no problem.

Curtis Dougan 6:53
So do you find if you're in a mall type setting, if it gets quite busy, does that impact how you get around?

Karen Medd 7:04
I'm not really busy doesn't bother me. Some stores are just too tight. You know, they're supposed to leave certain space but then they fill it up with baskets and boxes and displays and it's just not wide enough for some chairs. And so you're constantly thinking you're going to take something that and that that can be challenging people that doesn't bother me when it's too crowded,

Curtis Dougan 7:41
yeah, yeah. And I'm sure people are kind of not always paying attention or their

Karen Medd 7:46
people never pay attention. You kind of get used to that. Yeah, they walk around looking at a cell phone and don't even see you. Yeah,

Curtis Dougan 7:55
yeah, it's about being a defensive driver, right? Yeah, just like in the car.

Karen Medd 8:01
Exactly. Yeah. You have to drive defensively.

Curtis Dougan 8:05
Awesome. So on. If you could change one thing about your wheelchair. What would that be?

Karen Medd 8:22
That's a tough one. Because this chair is actually not bad. I mean, I've seen chairs that they have in Europe and stuff and some of them look really cool. But then I look at them and go, but they're not going to have some of the features I have. Like, I don't like my power chair in that it can't easily go up a small curve. You it doesn't. Whereas in the manual chair, you can sort of bounce up a

curb, right? You know you can do I don't know how to describe but when you push the wheel so that it pulls the up the front wheels up that then you caught the curb. Whereas in the power chair, I mean, first of all, it weighs so much, you know, the tenner itself weighs 350 pounds. So it's not like you can just bounce it up the curb. If the curbs there, you're stuck it's not accessible. In our small step into a store, you cannot go into it. So that's a little frustrating but at the same time, the reason my chair is heavy and has all that is because I have the ability to tilt it and have the ability to lift my legs up and extend them. I can lay flat if I wanted to. It also has the ability to go up and down in height. So I could be at the same height as someone standing, you know if you're at a cocktail party or something so that you're not everyone's bending down perspective. So once you put all of those options into the chair, it makes it a lot more comfortable and a lot more you know you can spend 10 hours in it and not have your back killing you. But at the same time it also makes it heavier, not as easy to maneuver as a manual chair but a lot more comfortable. So it's a trade off.

Curtis Dougan 10:23
interest as features are very interesting. Like I should definitely look into incorporating that into my

Karen Medd 10:34
part of my chair and it's a big part when I was like me years thinking it wouldn't work for me for those reasons. Because this chair, my old chair didn't have it. It has the ability to tilt because when I had a second surgery, I needed that one my back just if I can't if I have to sit upright the whole time it's very uncomfortable. So the ability to have it filtered recline a little bit, makes a huge difference when you're trying to sit in a chair for you know, 10 or 12 hours. In a day.

Curtis Dougan 11:04
Yeah.

Karen Medd 11:07
But having the ability to I noticed yours had the foot plate that could move. But if you could extend it up to put your feet straight out and get them it just allows you to move them during the day. So that they're not just sitting in one spot the whole day. Makes a big difference.

Curtis Dougan 11:29
So have it Yeah, move kind of up and down and forward and back and yeah, yeah, it's it's just mostly just

Karen Medd 11:38
goes mine goes. Yeah, I guess it kind of lifts up a bit and then straightens out so that I can put my feet straight out and raise them up because your circulation to when you're paralyzed isn't great. So to be able to get your feet up just gets the circulation. Moving a bit. Yeah. And I'm sure throughout the day, just swelling into everything.

Curtis Dougan 12:04

Yeah, and throughout the day, you don't want to I guess the key is Yeah, you don't want to be in the exact same position. entire day.

Karen Medd 12:13

No because I'm comfortable.

Curtis Dougan 12:17
That's excellent information. So is there any other kind of comments or feedback you would have based on the drawings that I sent you?

Karen Medd 12:29
The other question I had, I just know with my chair and with how I did transfers, handles lift up to get them out of the way. Because the way you transfer is you put a board between your chair and say your bed and you slide across it. So the handles are there. The pant get around here I mean like in my chair, my handles, I can lift them up and put them back so there's nothing beside me. So that then I put the board across and I slide across the board. That's how I get from the back to the chair. So you need to be able to have nothing in the way but at the same time. The other thing my chair has, well first of all, a lot of people depending on what level their injury is like mine is cheap three, so it's like chest level. So my core function, it's not great, but it's not too bad. Like I can keep myself sitting upright. I don't have to have a seat belt round near anything to keep myself afraid. But some people do. And I'm not sure what they care like that if you just have a wooden handle with the controls. If there's enough support around the body for some people you know, I mean, like most wheelchairs have a handle that goes across or keeps you from tipping over. The back is more formed to try to keep you give you that little bit of stability. So not everyone has a lot of trunk function. So either more kind of bolstering to the to the size of the seats or add some kind of bar on the side that just keeps you from slipping off the side.
Especially if you're going at a higher speed if you hit a bump. You know what I mean? You don't want something that's gonna cause you to lose your balance. Like one of the things I found when I first started driving that was hard for me, is when I go around and turn. If I go too sharp and too quickly, I can lose my balance in my chair driving. So that was something that I that was one of the hardest things I had getting used to. I was going too slow around the corners because I was scared of losing my balance of my body. Okay, and I have pretty good balance. So that's just one thing that some people would have an issue with.

Curtis Dougan 15:23
Excellent. Yeah, that's definitely something I'll I'll add in that's awesome.

Karen Medd 15:29
When I started to it's too bad. I didn't have the pictures earlier because I go to CCO twice a week and there's all sorts of different level injuries here and I would have been interesting to get some of their opinions or the therapists there with what they've seen and stuff. We can get them my best specializes in only does spinal injury patients. So yeah, I can definitely show them and get their opinions.

Curtis Dougan 16:03
Yeah, we can definitely have another call at a later date. Like if you

Karen Medd 16:09
go there every Tuesday and Thursday. That's why couldn't be Thursday's call. Yes

So anytime. I can take it to them and, and just get some more feedback and stuff. Just because there's more. There's they have a lot more like quadriplegics have some hand function but limited whereas I have full use my hands and arms and some of them are still in manual chairs. They have enough for that but not the dexterity in their hands and not quite the body control of the upper body. Always

Curtis Dougan 16:46
got the interesting for sure because things like are now on the hand controls I have like touchscreens may be better to simplify that and have maybe large buttons or something instead.

Karen Medd 17:01
Yeah, depending on the deck like I'm not sure. I know that when I had to do my driver's test, like I guess to drive this you wouldn't need to have a driver's license or would you? Like where does it fall in that sort of.

Curtis Dougan 17:17
So as you saw in the drive, you kind of connect to that outdoor vehicle that has like the windscreen and the kind of crash protection so that vehicle would be a biplane vehicle.

Karen Medd 17:32
So how does that it's almost like there was one that I saw what it was a similar idea, but not the same in there was in Europe, and it was sort of more along the lines of like a golf cart community type vehicle. So it couldn't go on roads, but it could probably go in bike lanes and they haven't one where you grow so they'll tear up into the vehicle.

Curtis Dougan 18:05
Yeah, through the through the rear.

Karen Medd 18:08
I think it was through the rear. Yeah, I remember looking at and thinking man, that tree could do it in a power chair. I think it would have had to be a manual chair. Yeah. Cool, but at the same time like I wasn't sure could have done winter here and they couldn't do like green lane the big road near us and stuff but Yeah, certainly was just another idea like that. But I don't know whether you have to driver's license for that kind of thing, because then it's a different test. And I'm just not sure how much injury can pass. A driver's test. And whether you need to cater to those people or not, you know what I mean?

Curtis Dougan 18:59
Yeah, no, I'm trying to keep it away from the driver's test, like keep it more as like, like a scooter or where you can just buy one like Canadian Tire and like a scooter you can my vehicle you probably won't be able to but it's like what the thesis like they say like don't worry about costs. Don't worry about like technology perfectly making sense. Like you can have it kind of like 10 years in the future kind of thing in terms of technology.
Karen Medd 19:30

So not too much the weeds. Yeah, I'm

Curtis Dougan 19:34
not gonna worry too much about cost and things like that. But yeah, things like the driver's license that is very relevant because it's like who can actually operate it is very important. Yeah, and I think what the controls I have right now, it would have to be someone who can operate the manual wheelchairs Well, if they had to, because they need that motor function. Yeah. Yeah, so yeah, I guess.

Karen Medd 20:08
Especially because if you live in somewhere like Toronto, there's much more bike lanes and stuff that could really make sense. You don't have the big roads that we have up here to get anywhere.

Curtis Dougan 20:21
Exactly.

Karen Medd 20:23
Yeah. And then it gives you the weather protection and stuff. Yeah, exactly. Yeah. No, it's like I say that when I saw in Europe, I thought, that's a really neat idea in the right setting, because it's small and it's easy to maneuver as far as you know, not having to drive a big vehicle. And when I saw that it was interested in it. It was before I got my license and was driving the minivan.

Curtis Dougan 20:51
Excellent. I know the one you're talking about, I think it's called the The kangaroo or something like that. And

Karen Medd 20:58
you remember it was a few years ago, but I remember because before I was driving,

Curtis Dougan 21:04
yeah, I remember what that one it has. It has like scooter controls with the handlebars that you turn left and right like a bicycle. Oh, yeah. So and yeah, then the rear entry, like the whole trunk opens up and it's this huge trunk and then there's a really steep ramp. Yeah, you drive up the ramp and into it type thing. So I'd have been a bit of an issue like when I was doing kind of product benchmarking and that I came across that one.

Karen Medd 21:38
But I remember seeing the care in Europe too, which we haven't seen here. That was more like the two wheels like what you're talking about. That turns I can't remember what it's called. I think it was in Sweden that I saw. But it Yeah, it had the more the tighter turning race ratios on the two wheels. Now it's something like that be in like gravel and they're not on pavement.

Curtis Dougan 22:10
So I'm thinking with when it's in just the two wheels. It would it wouldn't go very fast. So I'm hoping like, yeah, with gravel a pavement. It should be alright, but have thought about like bumps. And things like that. How to handle a bump.

Yeah. And not 100% Sure. And yeah, and gradually What if a wheel slips or something starts spinning.

Karen Medd 22:43
I know my chair. They sold it to me as being fabulous for going to horse shows and different things. Not so fabulous. It gets really bogged down and gravel and dirt and stuff. So the answer to that is I just I know that a lot of people are looking for something that they can you know, go with the family anywhere in a chair.

Curtis Dougan 23:12
Yeah, like I'm wondering if some kind of like speed limiter. Like say you're approaching gravel or dirt. If you can like hit a button, put it in like low gear like an off road truck or something like when it's really muddy. It limits how fast you can go so your wheels don't spin.

Karen Medd 23:34
Well and that's what my chair does. It puts it into a yellow. Okay mode on it when it hits that stuff. Okay, and you find that I don't know I don't know mechanically anything but then just frustrations that I have is trying to get through something that's not on pavement.

Curtis Dougan 23:55
So you find that yellow doesn't really work too well.

Karen Medd 24:00
Well, it does in that it stops the chair from getting me into trouble. It's just I wish it would just deal with it. It's like yeah, I recognize it's troubled too, but now I'm stuck.

Curtis Dougan 24:18
Yeah, yeah, no, I can imagine that's tough. But as

Karen Medd 24:23
I say, I do try to take it like a horse shows apple orchards, whatever, that are necessarily pavement and that's gotten stuck in my backyard a couple of times. And when you get a chair that weighs 350 pounds stuck. It's very hard to get unstuck because no one can just lift it up. Now it's got that weight plus the person and yeah, it can be really annoying.

Curtis Dougan 24:54
So how do you get unstuck, then?

Karen Medd 24:58
Oh, wow. I know I have a friend who's really really really strong. And he's come over twice and God man. And now I avoid all wet axes in my backyard when I know it's been raining. Because that's when they tend to get stuck.
Curtis Dougan 25:15
Yeah, interesting. So maybe I'll look into you know, like off road vehicles and see how they kind of deal with it and how do you how do you get unstuck? From mud

easily. That's an interesting challenge.

Karen Medd 25:31
It looks like something that you could take anywhere. So you want to take it anywhere, not just pavement, unless it's it unless you're really looking at it as being a sort of downtown urban get around in which case, you don't really have to worry about that. There's not a lot of dirt, lawns and stuff.

Curtis Dougan 25:56
Like, because for someone who does live in an urban area, like maybe they won't be able to take both pieces of the wheel at the pod as I call it and the wheelchair to like a horse show or something but it would be nice for them to at least use the wheelchair as a fully functional wheelchair just like every other wheelchair and be able to like operate a van or take a wheelchair trans bus or anything and go to a horse show if they please. They shouldn't have to own a second wheelchair to go visit their family up north or something. Right?

Karen Medd 26:37
Yeah. Well, that's the thing with this one. I know it showed the sizes and I'm just I'm really bad. I don't know what size my chairs but is it sort of the same dimensions as a normal chair?

Curtis Dougan 26:50
Yeah, it's, it's a bit shorter. Like, because there's no it's two wheels instead. of four. So

Karen Medd 27:00
it's not as long in the depths sort of?

Curtis Dougan 27:03
Yeah, exactly. Like from front to back.

Karen Medd 27:07
You're forgetting the round, but it's still as far as width. It's about same. Yeah, and the turning radius would be tighter. So like get riding when to get into a car wouldn't be a problem.

Curtis Dougan 27:21
No, I shouldn't be going in, in a van that was set up for wheelchair.

Karen Medd 27:27
Yeah, I would still want to maintain that function for sure. And what's what was the clearance on the bottom? Do you know what I mean? Like the clearance for like going up a curb onto your driveway or going over stuff on the road? I
Curtis Dougan 27:49
believe it's six inches sorry, my drawing in front of me.

Karen Medd 27:56
I'm really bad. Like I said, I don't know what mine is. And I know that what mine

has. It's pretty good. But then when I had something installed on the bottom of it that clicks into my into my van so that I don't have to use web restraints. Like it has a bottom lock. It's that it just clips into and D like I think it's called. Yeah, it just clicks in in the car so I don't have to strap and do all that crap

Curtis Dougan 28:30
driving. Yeah, you just drive right into them the clip clicks it Yeah, yeah.

Karen Medd 28:38
Is it put a little bit of extra on the bottom of my chair. So if I if I go up the curb that's not sloped enough. It scrapes on the bottom if they come up with a driveway at the end there's a couple spots that are fairly easy to come up number one I hear it scrape theater. I mean like if it's just too low, you end up scraping on a bunch of

Curtis Dougan 29:03
yes no good.

Karen Medd 29:05
Yeah. You just want to make sure there's enough clearance to go up into driveways like not normal curbs, but just ones that maybe aren't as sloped as others.

Curtis Dougan 29:18
So maybe I can have it. choke back somehow or like raise up for and just get over curbs.

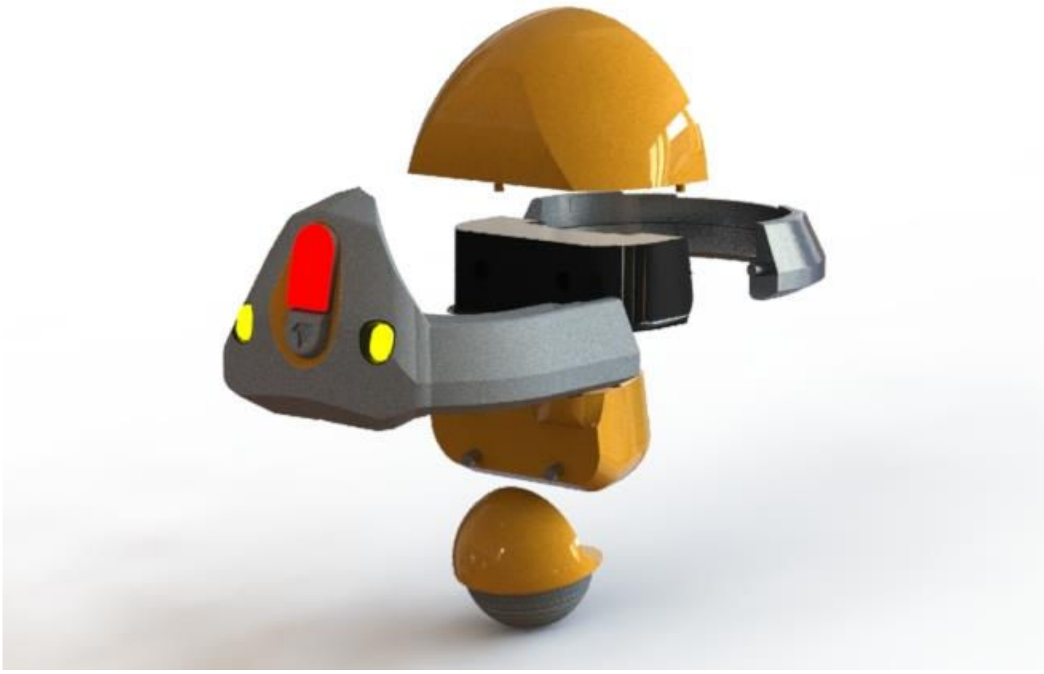
Karen Medd 29:27
Some just making sure that there's enough to accommodate crap in the road. You know what I mean? Yeah, yeah, you don't want to doesn't have to be a lot. It's just like I say just putting this one thing for my band. Makes it a little bit touchy sometimes.

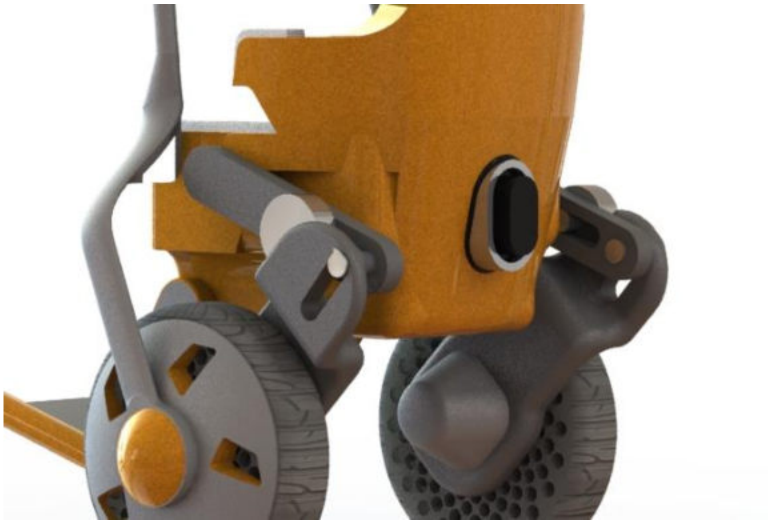
Curtis Dougan 29:45
You don't want to like run over a water model on the road and have it scraping all the way home.

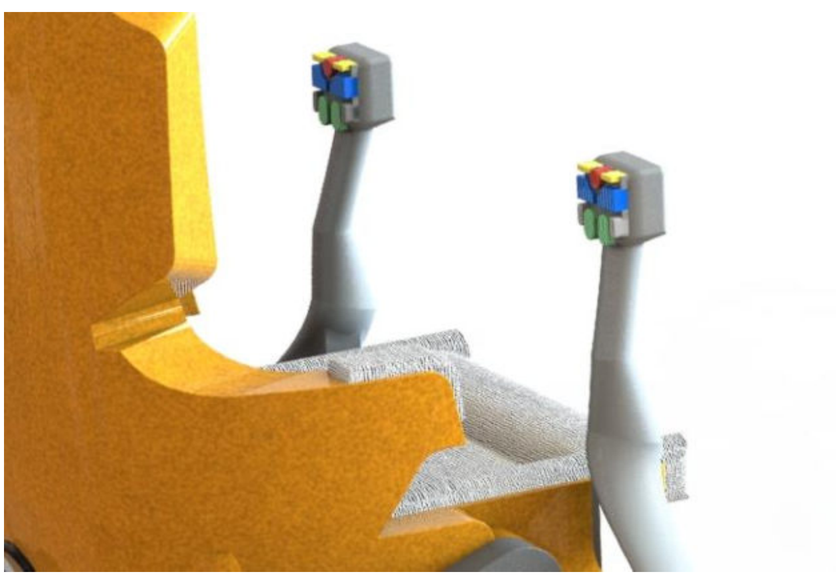
Karen Medd 29:53
Yeah, my dog's toys get stuck under my chair yes, one more thing that done twice drives me crazy that so?

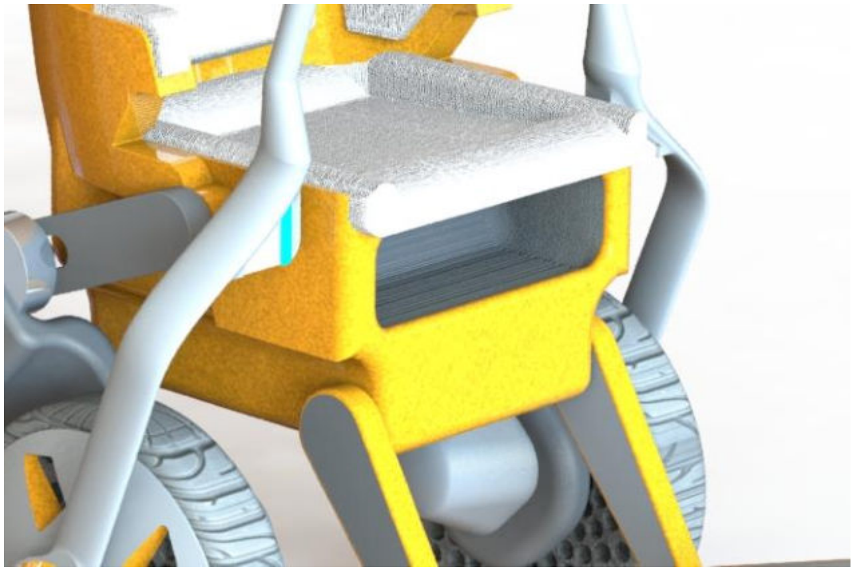
Transcribed by https://otter.ai

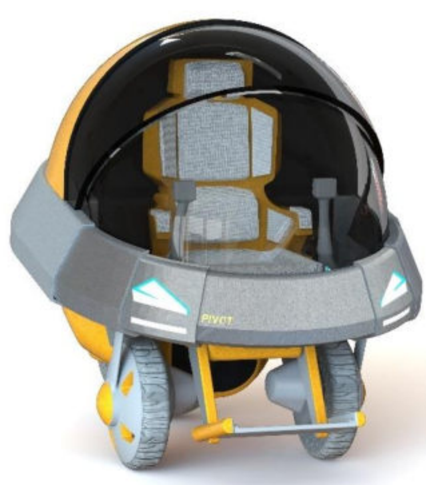
Appendix E – CAD Development



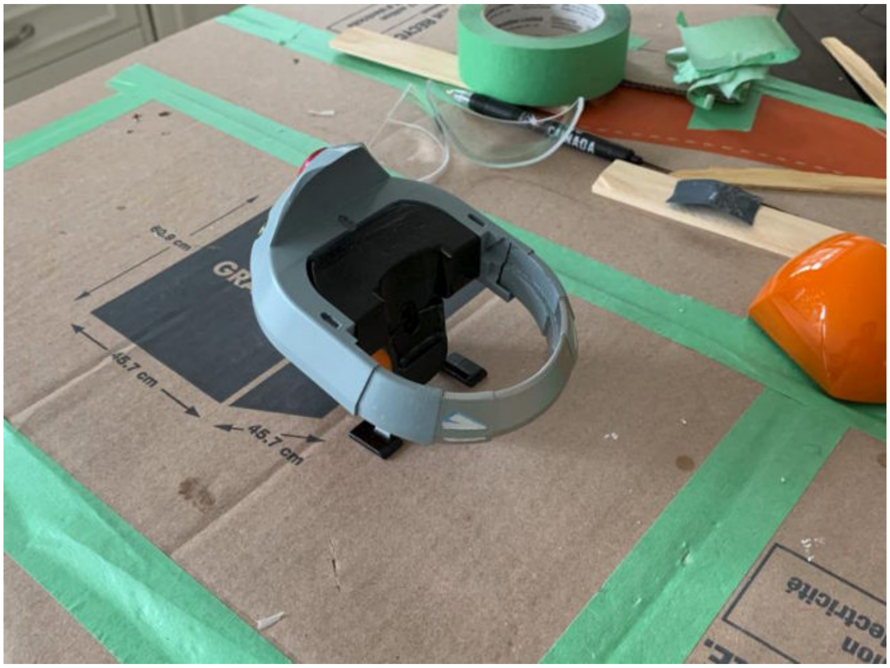







PIVOT

Appendix F – Physical Model Photographs


45.7 cm
45.7 cm


45.7 cm

Appendix G – Approval Forms & Plans

IDSN 4002
SENIOR LEVEL THESIS ONE

Humber ITAL/ Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2021
Catherine Chom:1 / Sandro Zaccolo

FTA-2 (B) THESIS TOPIC APPROVAL
This project/assignment constitutes 5% of total mark for the course

THESIS TOPIC APPROVAL (TOPIC DESCRIPTIVE SUMMARY):

Student Name:	Curtis Dougan
Topic Title:	How may we improve transportation for the physically challenged in urban areas?

Abstract

As we progress into the future, we strive to be more inclusive as a society. When envisioning vehicles for the future, designers repeatedly forget to include the physically disabled as users of self-driving vehicles. Current solutions for transportation have not been designed from the ground-up with these users in mind either. Steep ramps can cause shoulder injuries, complex mechanisms require more than one user to operate, and vehicles cannot be operated by all wheelchair users. The goal of this thesis is to improve transportation for the physically challenged in urban areas. Wheelchair users can feel isolated if they fear current transportation solutions cannot meet their needs. These users will search for living arrangements, jobs, and social circles that are immediately convenient instead of taking the risk of transporting through various environments. Environmental risks include congestion, physical terrain, and poor navigation. Using interviews and observational studies, these users' pain-points will be identified and a solution will be proposed that gives them the freedom necessary to ensure equality. Additionally, a scale model of the solution will be created in order to showcase the design. Contrary to previous years, when looking to the future, under-served communities must be identified and considered. By creating a vehicle accessible for all, the world can be opened up to a new group of users.

Student Signature(s):

Date: 26/09/2021

Instructor Signature(s):

Date:

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Chong, Kappen, Thomson, Zaccolo

IDSN 4502
SENIOR LEVEL THESIS TWO

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / WINTER 2022
Catherine Chong / Sandro Zaccolo

CRITICAL MILESTONES: APPROVAL FOR CAD DEVELOPMENT & MODEL FABRICATION

Student Name:	Curtis Dougan
Topic / Thesis Title:	URBAN MOBILITY FOR WHEELCHAIR USERS

THESIS PROJECT – DESIGN APPROVAL FORM

Design is reviewed and approved to proceed for the following:	[X] **CAD Design and Development Phase**
Comment:	- Initial CAD started well as of week #6/February 15th, continue with detailing and refinement. - Refinement CAD progress well as of week #8/March 8th, required to refine some detailing.

Design is reviewed and approved to proceed for the following:	[X] **Model Fabrication Including Rapid Prototyping / 3D Printing and Model Building Phase**
Comment:	- Once CAD is completed, can move forward to model fabrication from week #9 onward.

Instructor Signature(s):	Catherine Chong Sandro Zaccolo
Date:	8th March, 2022

PANEL ON
RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Curtis Dougan

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

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