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Mitigating the Physical Barriers of a Post-Secondary Education: Accessible Mobility Mapping and Rollshed Analysis for Vancouver Island University

by

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Abstract

This project provided the Vancouver Island University (VIU) Nanaimo campus with a detailed accessible mobility (AM) map and rollshed and routing analysis. The VIU campus consists of numerous steep pedestrian pathways that complicate the navigation of mobility-limited individuals. The goal was to mitigate physical barriers in the built environment by providing campus pedestrians with wayfinding and navigational information while simultaneously supporting the future AM work by VIU administration and facilities. Additionally, it was desired that the AM mapping methodology of this project be reproduceable for other institutions. First, a data typology was developed, and data was collected for several aids and barriers to AM. The data was refined into a campus map by categorizing pathway slope into accessible, steep and very sleep classes, and adding additional AM and ancillary information. The data was again refined to produce the rollsheds and AM routes. An average travel speed, path costs and path barriers were identified and used in a service area analysis to determine the distance a manual and powered wheelchair user could travel in a set amount of time. The map was released in September of 2019 and has reduced the amount of AM wayfinding and navigation questions received by Disability Access Services. The general methodology of the map is reproduceable, however it requires that an analyst make decisions that will ensure it depicts the most crucial barriers and aids to mobility found in the built environment. The rollsheds and routes highlighted AM weaknesses in the pedestrian network and is important information for the VIU administration and facilities to consider when discussing future plans for the campus.

1. Introduction

There are physical and institutional systemic barriers that can prohibit persons' living with disabilities from pursuing a post-secondary education (Hill, 1992). Examples of institutional barriers include brief class change times and a lack of specialized support to guarantee maximum participation in course work (Hill, 1992). Physical barriers can include stairs, curbs, steep pathway slopes, amongst many, and are typically more challenging to eliminate since modification of the built environment is required (Beale, Field, Briggs, Picton, & Matthews, 2006; Hill, 1992). Students still require mobility free of restraint, and many wheelchair users hesitate to explore unfamiliar areas and buildings if they do not have information about the built environment's accessible mobility (AM) aids and barriers (Thapar et al., 2004). An option for institutions is to develop a map dedicated to AM. While a map does not fix physical issues, it provides students with the resources necessary to plan their campus commute, limiting the wayfinding issues they encounter.

The collection of AM data and organization into pertinent public information is influenced by the design of the built environment and the AM needs of individual people; both tend to be highly variable across different localities, meaning there is a lack of a reproduceable AM mapping methodology. The development of a reproduceable method would aid post-secondary institutions to produce AM information for their staff and students.

Additionally, the dataset produced in the mapping process provides insight into the state of accessibility on a campus, which supports future efforts in disability-aid optimization. AM routing and service area analysis (also referred to as pedsheds and walksheds for walking pedestrians, and rollsheds for mobility-limited pedestrians) highlight the challenges faced by mobility-limited pedestrians and help determine where change should occur to reduce AM barriers.

This project employed Geographic Information Systems (GIS) to map and analyze the aids and barriers to mobility on the Vancouver Island University (VIU) Nanaimo campus. The goal was to support the navigation of mobility limited individuals, while simultaneously providing facilities management and administration with information that would promote the mitigation and potential removal of the campus's AM barriers. This goal was accomplished with two objectives. First, an AM mapping methodology was developed and an AM campus map was produced, focused on aiding individuals navigate the steep slopes found on the VIU Nanaimo campus. Second, the dataset collected in the mapping process was used to produce localized AM rollsheds and routes with a GIS-based routing algorithm. Manual and powered wheelchair (MWC and PWC) rollsheds were developed and compared to a walkshed, providing insight on how differently abled individuals are experiencing the campus.

2. Literature Review

There are several components involved in the development of AM maps and service area analysis, including typology development, data collection, data visualization, routing criteria and shed development. An in-depth investigation of each was required, with the results outlined in the following sections. The information reviewed guided the decisions described in the methodology. However, first an overview of critical disability studies, the term "accessibility", and how this project approached the concept of AM is required.

2.1 Defining Accessible Mobility

Accessibility is a broadly defined term, with Hansen (1959) describing it as "the potential of opportunities for interaction". Some disability activists have lobbied for the use of terms such as "Universal Access" and "Universal Design" over the years, referring to built environments that are optimized for use by individuals of all state and stature (Hamraie, 2016). Conversely, Hamraie's (2016) review of and contribution to Critical Disability Studies argues that this terminology and design consideration is aimed at hiding disability design, rather than making a conscious effort to actively include it. Enhancing the AM of individuals in the built environment should be treated as an open-ended process, a multimodal issue without an easily achievable endpoint (Hamraie, 2018). This project considers AM campus mapping as a separate and vitally important part of any accessible wayfinding plan, rather than assimilating disability AM mapping into a universal access method.

The definition of AM can also be broad, encompassing the needs of many individuals living with any type of disability. However, VIU has a complex route situation, with many steep, indoor and overhead pathways all needing to be effectively integrated into a network model. Therefore, a “stair-free” network was constructed, focused on optimizing routing for individuals with physical mobility disabilities. This project primarily serves wheelchair users but is also of use to individuals who use canes and those who cannot climb stairs. The mapping and routing performed in this project was not developed under the naïve assumption that it would be perfectly helpful for all individuals. The AM information derived from the data may not best serve individuals living with auditory, visual and other sensory impairments.

2.2 Mapping Accessible Mobility

2.2.1 Status of AM Campus Maps in Canada

AM maps for pedestrian navigation and wayfinding are an excellent idea in theory. Mapping ramps, slopes, curb cuts and other features empower the patrons of a school to appropriately plan their own routes and navigate around AM barriers. Nevertheless, many challenges complicate the cartographic process. Accessibility maps require a vast amount of data to be compacted and compiled into information, and appropriately displayed on an intuitive two-dimensional medium. Currently, less than 15% of accredited Canadian Universities have a dedicated static AM map. Approximately 43% of Canadian Universities provide a static map that integrates some accessibility features (for example accessible parking stalls, automated doors and curb cuts); 54% of campuses provide a static map variant with no AM information (Appendix A, Table A1). Some information is better than none, but the majority of the maps that were not dedicated to AM do not provide sufficient wayfinding information for mobility-limited users. Additionally, 60 web maps were explored on Canadian University websites. No web maps dedicated to access were found, and only twenty-five of these maps integrated some form of accessibility information (42%) (Appendix A, Table A1).

The scarcity of AM maps for Canadian campuses may relate to Canada lacking any accessibility legislation until Bill C-81 was assented on June 21st, 2019 (Bill C-81, 2019). The United States has had accessibility legislation since 1990, when they passed the Americans with Disabilities Act (ADA) (the most recent revision was 2010) (Americans With Disabilities Act of 1990, 1990; Department of Justice, 2010). Canada’s new access bill aims to reduce discrimination against persons’ living with disabilities, identify and eliminate barriers in the built environment and foresee and prevent future barriers (Bill C-81, 2019). Unfortunately, maps that promote AM wayfinding for public institutions are neither recommended nor enforced. However, the bill may motivate institutions to provide more resources to their staff, students and visitors, including access maps.

2.2.2 Producing Pedestrian Networks and AM Data Collection Methods

Pedestrian networks are generally used as reference base layers for AM maps. Several studies present methods of deriving these networks via the analysis of aerial images, semi-automated and automated buffering, ground tracing and other hybrid techniques (Ballester, Pérez, & Stuiver, 2008; Li et al., 2018; Karimi & Kasemsuppakorn, 2013). However, these derived networks generally contain too many errors for successful AM mapping and routing. The produced networks may have unconnected, missing or false pedestrian paths that can make AM maps unreliable. Fortunately, many universities have databases that include pathway networks. If unavailable, open source resources such as Open Street Map (OSM) contain pedestrian network data, which can be edited and exported by the public.

High quality AM data is required to ensure proper accessible route choice; substandard AM data quality can produce routes that are falsely labelled accessible (Tannert, Kirkham, & Schöning, 2019). Crowdsourcing AM data has been explored, but the positional accuracy and consistent description of mapped aids and barriers to mobility cannot be guaranteed (Hara, Le, & Froehlich, 2012; Menkens et al., 2011; Neis, 2015; Rice, Aburizaiza, Rice, & Qin, 2016). User-tracing and hybrid methods are also a possibility, but data quality concerns again arise (Frackelton et al., 2013; Palazzi, Teodiri, & Roccetti, 2010; Prandi, Salomoni, & Mirri, 2014). Properly executed ground surveys (Beale et al., 2006; Kasemsuppakorn & Karimi, 2009; Hayat and Fast, 2019) generate the most accurate databases. However, they are costly to produce in both time and money.

2.2.3 Developing an AM Data Typology

The development of a data typology streamlines the data collection and ensures no AM aid or barrier is left unmapped. Many research groups have developed their own data typology of AM aids and barriers and have used them to produce maps and facilitate AM routing. Matthews, Beale, Picton and Briggs (2003) and Beale et al. (2006) presented MAGUS, a wheelchair navigation system for pre-trip planning in urban areas. They surveyed wheelchair users in Northhampton, United Kingdom to build a mapping typology and determine AM routing impedances. The users were divided into three groups: manual assisted, manual self-propelled and motorized. They ranked ten barriers from one to ten, with one being the greatest impedance and ten being the least. While there was some variation across groups, the five highest-ranked barriers were deep gutters, narrow pavements, ramps/local slope, cambers and poor pathway maintenance. The four consistently ranked afterwards were raised manhole covers, fixed street furniture, unsupervised crossings and supervised crossings. Steps and high curbs were considered impassable and left out of the ranking system.

Sobek and Miller (2006) developed U-Access, a web-based system that routes mobility-limited individuals. The authors critiqued the complexity of typologies from other studies, claiming that such a high level of data was costly to acquire and maintain, and additionally unnecessary for the majority of routing issues. They simplified their typology to include travel distance, steps, curb cuts, sidewalk width and step height, ramp slope, ramp width, ramp turn radius, entrances and parking. They did not include level changes and pathway obstructions, nor sidewalk slope. While the data requirements for this model are less robust than others, this typology was too generalized and would not produce reliable AM maps and routes. Each barrier and impedance to travel should be accounted for.

Kasemsuppakorn and Karimi (2009) developed an AM typology that included travel distance, pathway slope, pathway width, steps, surface types, cracks, manhole covers, pathway traffic and uneven surfaces. Other pathway obstructions (plant overhangs, garbage cans, etc.) were not incorporated, rendering the typology less inclusive and less reproduceable.

Raiees-Dana (2012) built an AM campus map for the University of Arkansas based on a balance of slope and distance. Unfortunately, Raiees-Dana (2012) did not have the resources to collect data on sidewalk quality, limiting the effectiveness of the routes.

Hayat and Fast (2019) employed the ground-survey method to collect data for their comprehensive AM data typology and used it to map the University of Calgary, Mount Royal University and Southern Alberta Institute of Technology/Alberta University of the Arts campuses. The detail level of the typology was high; however, it was based on a subjective view of features being “accessible” or “inaccessible”, and subsequently labelled as such during data collection. However, features deemed inaccessible under this typology may still be crucial to accessibility wayfinding and require consistent data collection of its attributes to ensure a map and any subsequent analysis best represents the campus’s access situation. Thus, this subjective labelling of features limited the reproducibility of the approach.

2.2.4 Visualizing AM Data

The AM data needs to be refined into accessibility information to produce an AM map. Some studies simply map the shortest accessible paths between two routes based on their data and a routing algorithm that weights AM aids and barriers in the built environment (Matthews et al., 2003; Beale et al., 2006; Kasemsuppakorn & Karimi, 2009; Sobek and Miller, 2006). However, Kasemsuppakorn, Karimi, Ding and Ojeda (2015) noted that wheelchair users tend to take longer routes compared to the shortest feasible routes, likely due to preferred slope and sidewalk condition. These personal routes are likely to differ per person, since level of mobility can differ greatly per the individual. Therefore, it is important to present the entire AM network. This is achieved by mapping access scores or by categorizing features from an AM data set.

There are accessibility scores that quantify, compare and visualize AM data. Church and Marston (2003) discussed seven methods of producing accessibility scores (counting, total sums of distances, closest available, gross interaction potential, probabilistic choice, net and maximum benefit and absolute) and introduced another called relative accessibility. The Rick Hansen Foundation (RHF) Accessibility Certification is a rating system from 0% to 100% that evaluates the accessibility of a building, with 60% deemed accessible and 80% deemed certified gold (Rick Hansen Foundation, 2020). These accessibility metrics have their uses, but not necessarily for wayfinding. The individual characteristics of a barrier/aid are important in wayfinding, since a single barrier can prohibit travel from one destination to another. Therefore, the entire network of accessibility aids and barriers depends on every feature, since a single barrier can render a route inaccessible, regardless of how accessible the other features are.

Hayat and Fast (2019) categorized street crossings, percentage of accessible entrances per building, parking lots and sidewalk barriers. Accessible routes are not highlighted, making them hard to identify within the colorized features. However, the map was not created for accessible wayfinding, but rather to summarize the results of their data collection survey.

Raiees-Dana (2012) categorized the pathways of the University of Arkansas campus based on its' average slope. They used four slope classifications, founded on ADA recommendations: level (less than 2.86 degrees), ADA ramp slope (2.87 to 4.76 degrees), ADA steep ramp (4.77 to 7.3 degrees) and CAUTION: out of ADA range (exceeds 7.3 degrees). The categories were visualized in light green, dark green, orange and red colors, respectively. This empowered an individual to choose between different route options and was an effective way of categorizing AM information to enable pedestrian navigation.

2.3 Service Area Analysis ("Sheds")

2.3.1 AM Routing

Service area analysis for pedestrians is based on pedestrian routing algorithms, requiring the establishment of mobility impedances and path costs. Therefore, a review of AM routing endeavors is provided before a review of service area analysis. Beale et al. (2006) re-scaled the scores collected from their surveys and integrated them into a routing algorithm to produce AM routes. Steps and high curbs were considered prohibitive to movement and scored eleven so that the impedance score would produce a negative value and not be considered for routing. A user was able to select from the three mobility levels, and choose between six route types: optimum, shortest, fewest slopes, avoiding bad surfaces, limiting road crossings and only using crossings with lights (Beale et al., 2006). An issue with the study was that the algorithm and barrier weighting was not flexible, and therefore not highly reproduceable. The study area included pathways made from brick, grass, and other materials that were not always well-maintained. Therefore, pathway maintenance and surface type were important attributes in their cost-weighting. However, VIU has very few brick pathways, and all pedestrian areas are well-maintained. Additionally, grass and dirt pathways were not included in the VIU pedestrian network. Therefore, pathway surface type and quality would be excluded from the VIU routing algorithm.

U-Access was proposed as a web-based AM routing system that produces the shortest feasible routes for peripatetic pedestrians, walking pedestrians requiring aid and wheelchair users (Sobek and Miller, 2006). Therefore, three routing algorithms were developed, based on Sobek and Miller's (2006) typology. The peripatetic algorithm found the shortest possible route between destinations (Sobek and Miller, 2006). The algorithm for walking pedestrians requiring aid was programmed to avoid costly barriers (such as long staircases) but could incorporate smaller ones (e.g., short staircases). The wheelchair user algorithm produced routes that avoided barriers and limited other costs. These algorithms were appropriate for their three user types (Sobek and Miller, 2006). However, Sobek and Miller (2006) used a limited typology; potential pathway barriers may be unaccounted for, meaning some of the AM routes may be falsely labelled accessible.

Kasemsuppakorn and Karimi (2009) presented a routing methodology that addressed personalised routing for wheelchair users by considering environmental factors and user preferences. The process was complicated; the routing algorithm included adjacency matrices, fuzzification, comparison matrices and other complex steps. This process is not reproduceable for those not well-versed in GIS, mathematics and accessibility studies.

Raiees-Dana (2012) demonstrated the extra considerations of localized AM mapping and routing that was based on a single dominant mobility impedance. The University of Arkansas has many steep slopes. Therefore, the routing algorithm was weighted primarily on pathway slope, with distance the only other consideration. Other features were not including in the typology and therefore not incorporated in the routing. The methodology developed by Raiees-Dana (2012) was not robust enough to be reproduceable in any environmental setting.

2.3.2 Walksheds, Rollsheds and Bikesheds

Service area analysis produces a region that contains all "accessible" streets within a specified distance or amount of time (Esri, 2019). There are several types of service areas, based on different modes of travel. A walkshed (otherwise referred to as a pedshed or walkable catchment) is the area that a foot-pedestrian can access over a specified distance/time starting from a singular point (Sandalack et al., 2013). The simplest form of a walkshed is a constant-radius circle around a point, referred to as the straight-line or airplane method (Sandalack et al., 2013). This areal method is flawed since the movement of pedestrians is restricted to the infrastructure found in the built environment. A pedestrian must route around obstacles; they cannot travel straight through them. Two other area-based walkshed methods include the network buffer and line buffer techniques (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Oliver, Schuurman & Hall, 2007). The network buffer model calculates all possible end points along a road network and connects them, forming an irregular polygon (Frank et al., 2005). Evidently, this methodology remains problematic because it again assumes that all land within the polygon is traversable, even water bodies, private property and other impassable areas and obstacles (Sandalack et al., 2013). The line buffer technique measures the reachable end points in line distance and produces a buffer around the accessible paths, producing a more accurate representation of the traversable area (Oliver et al., 2007).

Daniel and Burns (2018) argued that these area-based polygon methods produced unrealistic analyses; mapping the actual pedestrian paths of a population provides substantially more information and aids the planning of pedestrian route networks to increase walkability. Additionally, it is vital to consider street connectivity and impedances to travel, such as topography effects and road crossings. Daniel and Burns (2018) most notably included topography effects in their walkshed. However, their GIS service area analysis model has its' limitations; they were not able to code the slope based on direction. Instead, Daniel and Burns (2018) performed return-trip analysis, rather than one-way analysis.

Walksheds do not model the movement of mobility-limited users. There are more impedances to travel for an individual living with a mobility disability that are not considered in a walkshed. A rollshed is a proposed form of service area analysis that is optimized to model the movement of individuals with significant physical mobility disabilities (i.e., wheelchair users). A rollshed determines how far that pedestrian can travel in a set amount of time, avoiding physical barriers such as stairs and curbs. Rollshed analysis is a novel concept, and therefore there is minimal foundational literature to review. Tajgardoon and Karimi (2015) produced a simulated network analysis that visualized the accessibility of the sidewalk segments within a network, providing tangible information on urban access issues. This hypothetically aids urban planners, designers and engineers to understand how the construction of the built environment influences AM for mobility-limited individuals. This is a natural outcome of a rollshed analysis; an analyst should determine where there is a lack of connectivity in the pedestrian network, influencing change to promote AM. However, a rollshed is based on timed movement across the network and does not provide information on the relative access of pathway segments.

There are similarities between bikesheds and rollsheds. Slope steepness, road surface quality, street connectivity and density, weather and traffic conditions are impedances for cyclist travel. These factors can slow their commute and cause them to expend more energy (Iseki and Tingstrom, 2012). Nevertheless, there is a distinct difference between rollsheds and bikesheds: the effects of uphill versus downhill slopes. The presence of more downhill slopes increases the size of a bikeshed, while uphill slopes cause a decrease in size (Iseki and Tingstrom, 2012). Alternatively, both uphill and downhill slopes result in a decreased rollshed size. The presence of a steep slope, uphill or downhill, forces a wheelchair user to reduce their travel speed significantly (Richter, Rodriguez, Woods, and Axelson, 2007; Corfman, Cooper, Fitzgerald, and Cooper, 2003; Cooper, Dvorznak, O'Connor, Boninger, and Jones, 1998).

2.3.3 Determining Travel Speed and Stair/Slope Impedances

Table 1: Walking, MWC and PWC speeds from previous studies.

	Travel Speed (km/h)		
	Walking	**MWC user**	**PWC user**
Laplante & Kaeser (2004)	4.40		
Browning et al. (2006)	5.11		
Mohler et al. (2007)	5.07		
Daniel & Burns (2018)	4.80		
Khahk, Fast & Shahid (2019)	4.80		
Ikeda and Mihoshi (2003)		3.9	4.3
Tolerico et al. (2007)		3.5	
Gagnon et al. (2015)		4.2	
Cooper et al. (2002)			1.08 - 2.16 avg, 9.72 max

A travel speed is required to determine distance covered during a set period of time. This project needed three speeds: average walking speed, average MWC user speed and average PWC user speed (Table 1). Several studies have investigated average pedestrian walking speed. Laplante and Kaeser (2004), Browning, Baker, Herron, and Kram (2006) and

Mohler, Thompson, Creem-Regehr, Pick, and Warren (2007) suggested 4.40 km/h, 5.11 km/h and 5.07 km/h, respectively. Walksheds have traditionally used a value of 4.80 km/h, used in the studies of Daniel and Burns (2018) and Khakh, Fast and Shahid (2019).

Ikeda and Mihoshi (2003) measured a short-distance road crossing average MWC user speed of 3.9 km/h, while Tolerico et al. (2007) found a long-term daily average of 3.5 km/h. Gagnon, Babineau, Champagne, Desroches and Aissaoui (2015) tested MWC users on a treadmill and reported an average comfortable travel speed of 4.2 km/h. Ikeda and Mihoshi (2003) also reported the average speed of PWC users crossing roads in their study (4.3 km/h). Cooper et al. (2002) studied the driving characteristics of three PWC user groups over the course of five days and determined a daily average travel speed of 1.08 km/h to 2.16 km/h. They reported that the maximum travel speed of the groups was 9.72 km/h. The study accounted for all types of movement and likely underestimated the average travel speed of the individuals.

Travel speeds will vary, depending on the impedances a pedestrian has to navigate. Stairs and slopes slow down a pedestrians walking speed in a walkshed (Daniel and Burns, 2018; Kretz et al., 2008). Therefore, the basic travel time needs to be scaled appropriately. Nevertheless, slope was not used as an impedance in the walksheds, due to the complications discussed by Daniel and Burns (2018). However, steps were considered a cost factor, therefore staircase travel speed was investigated. Kretz et al. (2008) found an average travel speed of 1.52 km/h, 1.38 km/h and 1.29 km/h for three test groups on long staircases. They also determined that the horizontal upstairs travel speed of pedestrians on short staircases (approximately 4.4 metres) was twice as fast as the travel speed on long staircases (Kretz et al., 2008). Choi, Galea and Hong (2013) studied the travel speed of individuals climbing stairs in a Korean high-rise building. The average ascent and descent speeds of their male and female test populations were 2.38 km/h and 2.99 km/h and 1.73 km/h and 2.66 km/h, respectively. Notably, their test population was relatively young, which may have skewed the results to a higher average. Regardless, these studies demonstrated that the presence of stairs slowed the travel of a pedestrian.

Travel speeds of pedestrians in a rollshed are affected by pathway slope. However, the impact of slope differs for MWC and PWC users. Ackermann, Leonardi, Costa and Fleury (2014) demonstrated that propulsion effort and energy expenditure of an MWC user increases exponentially with increasing slope. Richter et al. (2007) studied the stroke pattern of MWC users on flat ground and varying slopes. They determined that self-selected velocities were 1.5 and 2.7 times slower when propelling up three- and six-degree slopes, respectively, compared to flat ground. The study consisted of fit, younger males with spinal cord injuries, and therefore the results do not represent a diversity of sex and age. Arabi, Aissaoui, Rousseau, Bourbonnais and Dansereau (2004) compared the relative mechanical demand of an MWC user during up hill propulsion over slopes of 2.7, 4.8 and 5.7 degrees. They determined that the relative mechanical demand was significantly higher for the steeper slopes. Gagnon et al. (2015) tested a diverse group of MWC users to evaluate trunk and shoulder kinematic and kinetic and electromyographic responses and adaptions to increasing slopes at a constant speed. A notable outcome of their study was that many of their users failed to complete a 20 m trial run at their preferred travel pace as the slope was increased. All of the users completed their trials at 0 and 2.7 degrees, while 88.9%, 77.8% and 55.6% of the users completed the test at 3.6, 4.8 and 7.1 degrees, respectively. These studies showed that the pace of travel of an MWC user decreases significantly, and potentially stops, as slope increases. Therefore, the slope impedance in the MWC user shed needs to be implemented accordingly.

PWC users employ motorized propulsion systems and are therefore unlikely to physically fatigue when navigating the built environment; low and moderate slopes are not considered impedances to PWC users. Nevertheless, large slopes are a safety concern. Corfman et al. (2003) investigated tips and falls during PWC usage. They demonstrated that there is potential loss of PWC control at 1-2 m/s on a five-degree slope, and that it is more prevalent in the downslope direction compared to upslope. According to Cooper et al. (1998), users of PWCs can have difficulty maintaining a seated posture when subjected to external forces, such as the navigation of slopes and curb cuts. These two studies are evidence that PWC operators must slow down on steep slopes or risk an accident.

3. Methodology

3.1 Study Area

The project was based in Nanaimo, B.C., on VIU's main campus (Figure 1). The Nanaimo campus has a student population of approximately 14,500, with 68 buildings built across 110 acres on a hill that leads into Mount Benson (Vancouver Island University, 2020). The elevation

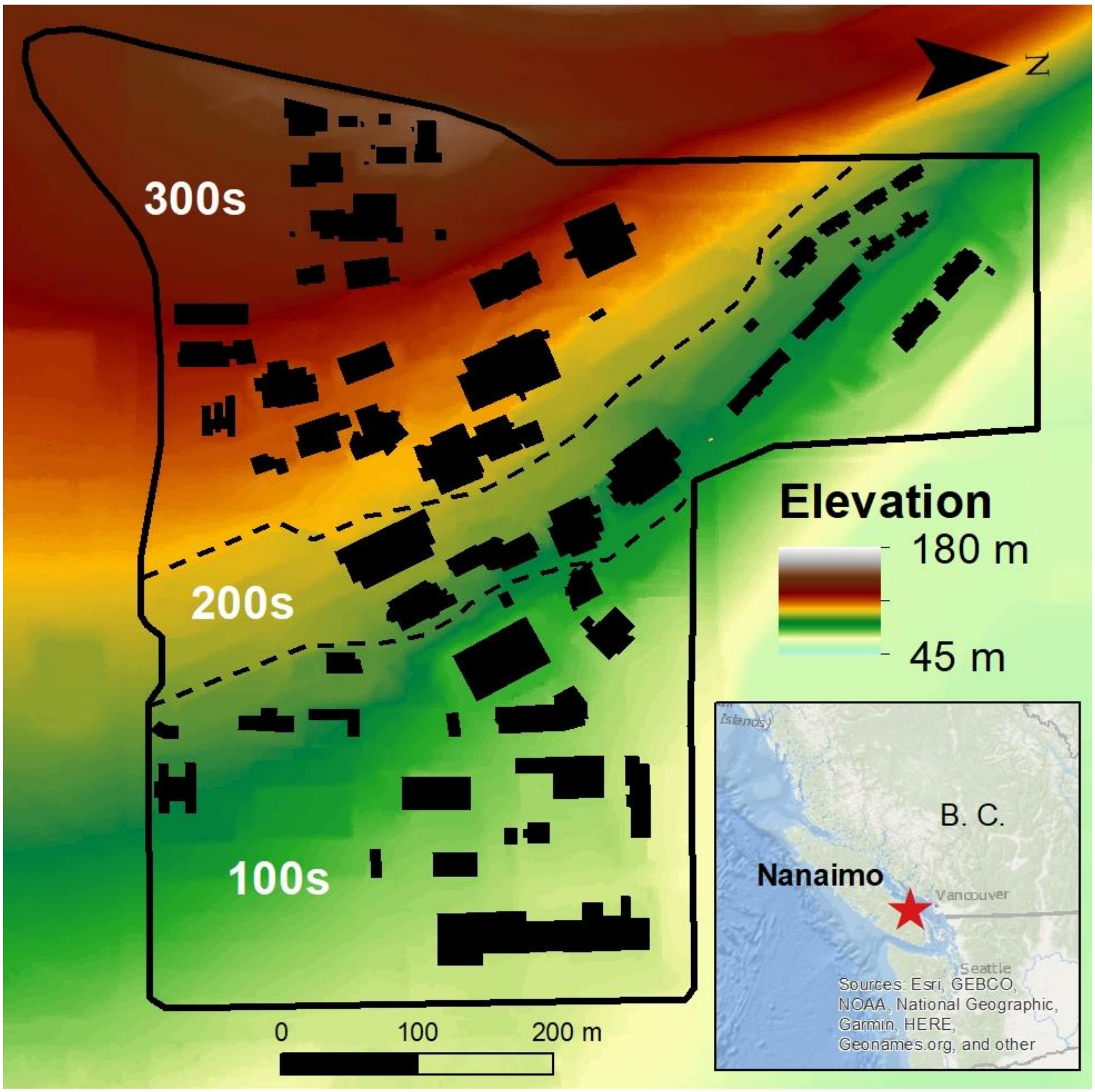

Figure 1: The VIU main campus, located in Nanaimo on Vancouver Island, B. C. The black polygons represent buildings. From bottom (East) to top (West) there is an increase of approximately 120 metres.

increase across campus is approximately 120 metres from the bottom (East side) to the top (West side). There are three campus levels: the 100s, 200s and 300s, the Eastern, central and Western portions of the campus, respectively (Figure 1). The pathways between the campus levels, and sometimes within, tend to be very steep, usually requiring the navigation of elevators and staircases. In many cases, interior pathways through buildings provide the fastest and safest routes.

3.2 Data Collection

3.2.1 Pedestrian Network Data

VIU facilities management and the VIU Geography department could not supply a vector-based pedestrian path network for the Nanaimo campus. A CAD file was provided, but there were gaps in its pathway network and therefore it was deemed unreliable. Rather, a pedestrian path network for VIU was initially edited by the mapping team on OSM, then exported into ArcMap for further review. The coordinate system for the data (and all resultant visualizations and analysis) was set to NAD83 UTM Zone 10N upon import into ArcMap. Every individual pathway segment was analyzed, and any problematic areas were validated with ground surveys. Care was taken to confirm overhead walkways did not intersect with the pathways below. These measures ensured a complete and accurate outdoor pathway network. Next, interior pathways used to navigate between campus levels were identified, manually digitized and saved in a feature class. It was ensured that they were accurately connected to exterior pedestrian paths.

3.2.2 Typology and AM Data Collection

Campus employees and students were consulted before the typology was developed. The common theme from the consultation was that AM information (PDF maps, web routing maps, etc.) would help many individuals, not only those who are mobility limited. For example, catering and information technology personnel transporting carts with heavy goods have to avoid stairs and would benefit from having information on where the flattest routes are.

Table 2: The AM data typology, i.e., the features and their respective attributes recorded during the data collection. A definition of the features and their attributes is provided in Appendix B.

Feature	Attributes
Level Change	Type, Pedestrian pathway clear space (m), Height (cm), Width (cm), Length (cm)
Metal Cover	Type, Width (cm), Length (cm), Openings width (cm), Perpendicular to pedestrian pathway, Flush to ground, Height (cm)
Curb Cut	Width (m), Length (m), Running slope (°), Cross slope (°), Texture contrast, Marked, Landing pad size, Perpendicular to path, Contained within markings, Projects into vehicle area, Flared sides, Flared side slope (°), Stub-toe, Stub-toe height (cm), Surface type
Curb Drop	Marked, Perpendicular to path, Contained within markings, Projects into vehicle areas
Door	Type, Access, Width (cm), Opener, Handle, Leads to interior stairs only, Leads to exterior stairs only, Leads to manual doors, Clear space (cm), Lip (cm)
Campus Map	Height bottom (m), Height top (m), Size (m*m), Sign distance (m), Map character size (mm), Wayfinding character size (mm), Approachable and readable, Glare-free surface
Accessible Parking Stall	Width (m), Adjacent to access aisle, Total width (m), Distance to entrance (m), Adjacent to curb cut/ramp, signage, slope (°)
Pay Machine	Type, Height top (m), Height bottom (m)
Elevator	Type, Entrance width (m), Width (m), Length (m), Operating hours, Access to all floors, Handrails, Handrail type
Tactile Indicator	Indicates, Width (m), Length (m)
Path Barrier	Type, Pedestrian pathway clear space (m), Length (m), Width (m)
Assistance Phone Kiosk	Button/pad height (m), Speaker height (m)
Problematic Pedestrian Pathway	Width (m), Length (m), Shared use, Surface type, Passing spaces, Passing space interval (m), Edge protection, Avg/Max running slope (°), Avg/Max cross slope (°)
Trail	Width (m), Length (m), Shared use, Surface type, Passing spaces, Passing space interval (m), Edge protection, Avg/Max running slope (°), Avg/Max cross slope (°)
Crosswalk	Width (m), Length (m), Type, Running slope (°), Cross slope (°), Curb cuts, Surface type, Marked
Curb Ramp	Width (m), Length (m), Running slope (°), Cross slope (°), Texture contrast, Marked, Landing pad size, Perpendicular to pathway, Contained within markings, Projects into vehicle area, Stub-toe, Stub-toe height (cm), Surface type
Steps	Width (m), Length (m), Handrails, Handrail type, Handrail bump, Edge protection, Curved/Circular, Marked, Rest areas, Rest area interval (m), Surface type
Ramp	Width (m), Length (m), Avg/Max running slope (°), Avg/Max cross slope (°), Handrails, Handrail type, Handrail bump, Edge protection, Curved/Circular, Rest areas, Rest area interval (m), Landing pad size, Surface type

The typology was designed to completely and consistently collect data for all the features deemed important to AM wayfinding. Eighteen features, and their respective attributes, were identified (Table 2; Appendix B). An example of a feature was problematic pedestrian pathways, considered any pathway that had an identifiable AM issue, including but not limited to a steep slope and missing edge protection. Average and maximum running and cross slope were recorded for each line in the problematic pedestrian pathway feature class. Other examples of features included in the typology were curb drops, steps, ramps, curb cuts, accessible parking stalls and elevators. The definitions for each feature and their attributes are included in Appendix B.

The VIU AM data was collected, managed and visualized with Esri software products. ArcGIS Desktop V10.6 was used to create empty feature classes for each member of the AM typology. The feature classes were uploaded to the VIU ArcGIS Online organizational account and added to a blank web map. Next, geospatial reference information was added to the web map to ensure accurate feature geolocation. OSM was employed as a base map since VIU lacked a detailed geodatabase for the campus. Finally, the data was collected by a mapping team of community planning graduate students and GIS technicians equipped with mobile phones and Esri's Collector application. Laser measures, tape measures and digital levels were used to record and measure the slope, width and length of several accessibility features. Data was instantly uploaded to the VIU ArcGIS Online server. Digital photographs were captured for each feature and stored with the feature data on the ArcGIS Online map.

A challenging aspect of the data recording was ensuring the mapping team was consistent with their observations and measurements. Care was taken to ensure that the team viewed features with an "eye for access", to promote complete and consistent collection of data. Mapping was always performed in pairs or groups to encourage discussion on features that were challenging to measure. Additionally, group discussions were periodically held to gauge progress of the feature collection. Nevertheless, comprehensive data cleaning was required to correct the occasional error. Every feature was examined to ensure proper geolocation and the consistency of attribute values.

3.3 Developing the Campus Map

Figure 2 provides an overview of the AM campus mapping process. The greatest hinderance to mobility at VIU was the steepness of the campus. Presenting this information to the public was deemed most important to helping mobility-limited individuals navigate the VIU Nanaimo campus. Therefore, the AM campus map focused on pathway slope. As discussed, running and cross slope values were collected for three feature classes representing paved/wooden pathways: problematic pedestrian pathways, ramps and crosswalks. These slope values were added to the pedestrian network derived from OSM, in an effort to collate all the data into one feature class. Running slope was the best option for display on the map, since it tended to be the steepest. However, some cross-slope measurements were used in special cases where the camber of the pedestrian pathway was dangerously steep (i.e., the crosswalk between student housing and the main campus). Additionally, average slope was chosen over maximum since average slope was a better representation of the path as a whole.

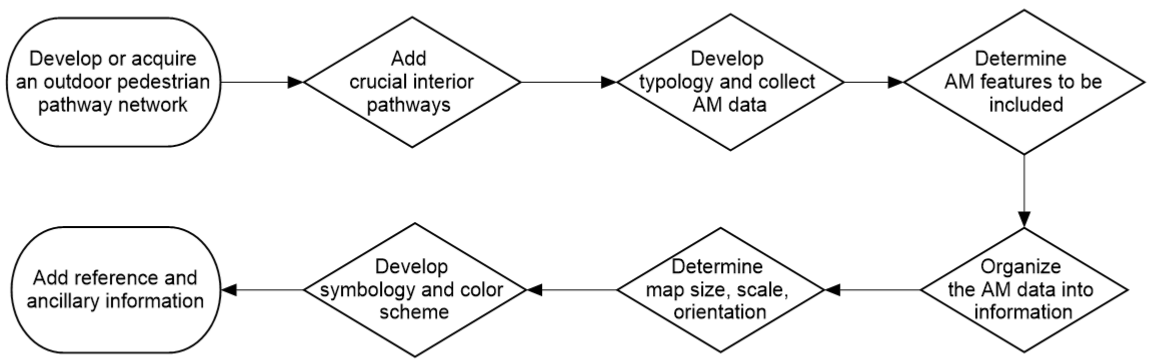

Figure 2: A high-level overview of the AM campus mapping process.

This project categorized all levels of accessible routes on the map, comparable to the efforts of Raiees-Dana (2012). The pathway segments in the derived pathway network were divided into four categories: others, accessible slopes, steep slopes and very steep slopes. Pathways in the other category led to dead ends and stairs, and therefore were not important to AM wayfinding visualization. Accessible slopes, steep slopes and very steep slopes were any pathway with an average slope of zero to 4.7 degrees, 4.8 to six degrees and 6.1 to fifteen degrees, respectively. Evidently there were no slope measurements for the unproblematic pathways in the network; these were assumed to be less than 4.7 degrees and included in the accessible slopes class. The accessible route slope range was chosen based on a review of the ADA and RHF access standards (Department of Justice, 2010; Rick Hansen Foundation, 2018). The range for the steep and very steep slopes was based on a manual review of the data. Changing the ranges for slope steepness would drastically alter how the map looks. Care was taken to ensure the selected ranges did not make the campus appear steeper or flatter than it would feel in person. Finally, the accessible, steep slopes and very steep slopes categories were further subdivided into four groups: routes, overhead walkways, routes through traffic and indoor routes.

Other features needed to be plotted on the map to produce an effective AM navigational tool. However, displaying all eighteen features would clutter the final product. Therefore, only seven additional feature classes were incorporated into the map: doors (only power operated doors), accessible parking stalls, elevators, assistance phone kiosks, trails, steps and ramps.

Next, the map framework was determined. An 11”x17” page size was used since a standard letter-sized page was too small to show the intricate details of the pedestrian route network. Furthermore, the frame was rotated 272 degrees to display the map in a portrait orientation. The staff and students are most comfortable viewing the campus in an East to West fashion, not North to South. Lastly, the student housing area was cropped from the main map and made into its own standalone map. Including student housing on the main map would increase the map scale, making symbols smaller and harder to read.

Next, symbology and a color scheme were developed for the map contents. A green/yellow/red scheme for the accessible, steep and very steep slopes was initially considered, but there were concerns over green/red colorblindness. Therefore, accessible slopes were colored blue instead of green. Steep slopes were colored yellow and very steep slopes red. The pedestrian pathways in the others class were set to grey. Unique line symbols were also chosen for routes, overhead walkways, routes through traffic and indoor paths. Ramps were represented as two parallel black lines with empty space in the middle. The color-coded network path filled this empty space, allowing ramps to be distinguished regardless if they were on an overhead or ground route. Power doors were visualized as dark-green circles that included the floor number within. This was important due to the steepness of the campus, and the confusing nature of the indoor pathways. In many cases, an individual might leave the first floor of one building and directly enter the second or third of another. This can perplex pedestrians and make wayfinding and navigation more challenging. The other symbols were meant to be intuitive. The wheelchair access symbol is commonly associated with accessible parking stalls and was therefore used in this map. A black elevator symbol was used for elevators, again an intuitive choice.

Lastly, a white background was deemed least distracting and the least visually straining. Most reference information (buildings, roads, parking lots, other pedestrian streets) was greyed to develop visual hierarchy within the map. The reference information fades into the map background, allowing the colored access features to be the first piece of information that many map readers will notice. Labels for buildings, important roads, parking lots, other amenities and campus entrances and exits were added; ancillary information (a legend, building list, and others) were positioned on the edges of the page around the map body.

3.4 Producing the Walksheds and Rollsheds

The following subsections outline the production of AM service area analyses and routes. A high-level outline is provided in Figure 3.

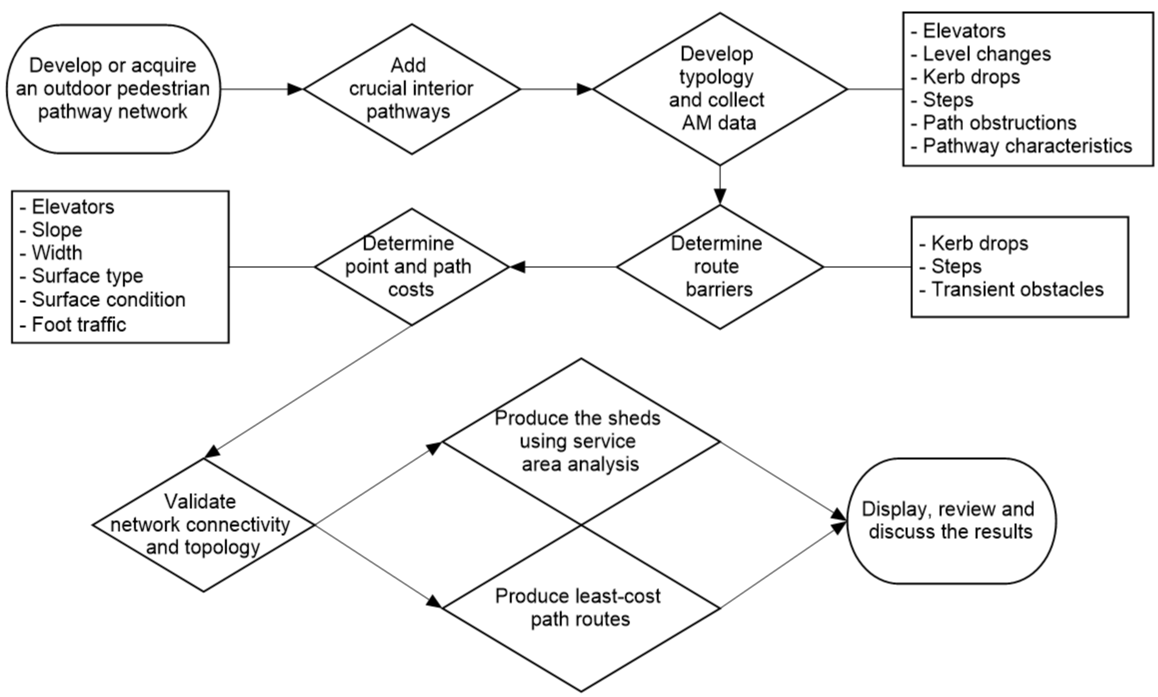

Figure 3: A flowchart outlining the critical steps involved in service area and routing analysis, starting with the acquisition of data and ending with the production of cartographic information and knowledge derivation.

3.4.1 Service Area Analysis Unique Data Requirements

The production of an AM campus map does not require the measurement of every slope on campus, only the ones deemed problematic. Therefore, slope measurements were missing for many of the stair and curb drop free pathways in the pedestrian network created for the AM map. The remainder of the slopes were derived via two methods; a high-resolution digital elevation model (DEM) and an advanced knowledge of the study area. A LiDAR point cloud was downloaded from the Nanaimo Open Data portal and opened in ArcScene 10.7. Trees, buildings and other above-ground objects were removed, leaving a model of the ground surface. This model was exported as a 2m-DEM and imported into ArcMap. Pathway slope was added to the unmeasured segments in the pedestrian network, using the "Add Surface Information" tool. Unfortunately, the slope of pathways directly underneath or adjacent to the buildings were miscalculated, and generally had a slope value that was unrealistically high. Therefore, these pathways were given a slope of one degree, since ground reconnaissance of the area determined that building entrances and adjacent pathways were overwhelmingly flat.

3.4.2 Determining Barriers and Deriving the Path Costs

Table 3: AM data essential to determining path barriers and costs in a routing network.

Required Data	Description
Elevators	An enclosed automated device that lifts/lowers individuals from one level to another.
Level changes	A significant change in the level of a footpath. Only recorded if greater than 2.5 cm.
Curb drops	A point along a pathway where a curb cut/ramp would be required to negotiate small elevation changes, i.e. wherever an exterior path of travel encounters a curb (City of Calgary, 2016).
Steps	A set of flat and continuously elevated surfaces at ninety-degree angles that facilitate movement from one level to another. Cannot be negotiated safely in a wheelchair.
Pathway obstructions	An above ground feature that reduces effective pathway length below 1.5 metres, potentially impeding pedestrian travel.
Pathway characteristics	The slope, width, surface type, surface condition of all pathways involved in the network need to be measured. If possible, a measure for foot traffic should also be recorded.

A modified data typology was developed to determine the barriers and impedances in the service area and routing analyses; Table 3 summarizes the basic AM data requirements for determining the path barriers and path costs in the rollshed and walkshed analyses. The steps feature class was converted from polylines to points to speed up processing time in the rollsheds. A step point was digitized on each end of the steps.

Previous AM studies provide vague definitions of what constitutes an AM barrier. According to this research, pathway AM barriers represent any feature in the built environment that stops a pedestrian's travel. It would be impossible to traverse a barrier; a pedestrian would be forced to reroute. Additionally, barriers can be subjective, based on the mobility level of the pedestrian. No path barriers were added in the calculation of the walksheds.

For baseline mobility-limited users (i.e., wheelchair users), four types of potential pathway barriers were identified (described in Table 3): Level changes, curb drops, steps and pathway obstructions. Steps and curb drops are permanent and should be included in any rollshed as pathway barriers. However, there is flexibility in the implementation of the other two. Each individual feature from the level change and pathway obstruction feature classes should be manually analyzed to determine if their inclusion is required. VIU facilities management is proactive in removing transient barriers, including many level changes (potholes, tree roots, etc.) and path obstructions (plant overhangs, garbage cans, etc.); the majority of these were not included in the rollsheds. Only one pathway obstruction was included as a pathway barrier: a large patch of deep gravel covering a sidewalk North of building 165. Other transient obstacles, such as construction sites, were additionally ignored.

There are additional impedances that do not fit the pathway barrier definition, since they merely slow pedestrian travel and do not stop it. These are categorized as point and pathway cost factors. The elevators feature class was the only point cost factor in both the walksheds and rollsheds. Travelling through an elevator delayed the progression of simulated travel by two minutes, an approximation of VIU's general elevator wait and usage time.

A pathway cost factor should be added to each individual path in the pedestrian network, based on the collected pathway characteristics. The cost would be scaled by the length of the path and the value of the cost. As discussed in the literature review, common impedances in a walkshed include road crossings and pathway slope (Daniel and Burns, 2018). Road crossings were excluded from this study since there were very few, and many were not in high traffic areas. Pathway slope was also not implemented, because of the issues discussed by Daniel and Burns (2018). Instead, the influence of staircases was weighted as an impedance. However, scaling travel speeds based on stairs is a complicated endeavor (Kretz et al. 2008). For the walkshed, the speed of travel on stairs was scaled to a rate of 2 km/h on stairways larger than 6m in horizontal length. Travel speed on shorter staircases was not scaled.

The pathway impedances that should be considered for a rollshed are pathway slope, width, surface type, surface condition and foot traffic. The influence of the five factors on a locality should be examined, and their cost weighted accordingly. For the VIU Nanaimo campus, only the slope measurement was included, and the slope factors for uphill and downhill slopes were weighted in an identical manner. The following set of equations were developed based on the evidence of wheelchair/slope interactions covered in the literature review. Equation 1 calculated pathway costs for the paths in the MWC rollsheds with average slopes between zero and eight degrees , respectively:

$$Eq. 1: \qquad \frac{Avg.\ Slope^{1.7}}{10} + 1$$

Pathways with average slopes under 4.8 degrees were not considered an impedance for PWC rollsheds. However, slopes larger than 4.8 degrees needed a scaled cost since they present safety issues to PWC users. Equation 2 derived costs for pathways with average slopes larger than 4.8 degrees and less than eight degrees in the PWC rollsheds:

$$Eq. 2: \qquad \frac{Avg.\ Slope^{2.7}}{100} + 1$$

Equation 3 produced scaled costs for all paths with an average slope greater than eight degrees in both the MWC and PWC rollsheds:

$$Eq. 3: \qquad \frac{Avg.\ Slope^{4}}{100} + 1$$

These equations scaled the pathways in an exponential fashion, with steeper pathways slowing the travel speeds of pedestrians at a higher rate than moderate slopes. A constant was added to each equation to ensure the costs were always greater than one.

Of note, these pathway cost impedances generalize the effect of slopes on wheelchair users. The MWC rollshed model is a general approximation that will not reflect the individual preferences and abilities of pedestrians. MWC users have different stamina and strength levels. Some pedestrians would be able to navigate the campus faster; some would not be able to navigate it at all. This is the same for PWC users; some would feel more comfortable travelling at faster speeds, while some would prefer a slower pace of travel.

3.4.3 Creating the Routing Network

Table 4: The topology rules implemented to ensure there were no errors within the network.

#	Feature Class(es)	Rule
1	Steps (points), Pedestrian network (lines)	Point must be covered by line.
2	Curb drops (points), Pedestrian network (lines)	Point must be covered by line.
3	Pathway obstructions (points), Pedestrian network (lines)	Point must be covered by line.
4	Pedestrian network (lines)	Must not have dangles.
5	Indoor pathways (lines)	Must not have dangles.

Topology rules were implemented to eliminate barrier placement errors and network disconnections in the AM routing network (Table 4). The “point must be covered by line” rule validated the locations of all path barriers. These point barriers were required to be directly on top of an outdoor pathway, otherwise they would not stop travel in a routing calculation. The “must not have dangles” rule ensured that there were no disconnections between the end points of the pathway lines. Disconnected line errors produce barriers in the model that do not exist in the built environment. There were over 350 topological errors upon initial validation; they were individually corrected or marked as exceptions.

Next, the service area network was created by combining the outdoor pathway pedestrian network and indoor pathways feature class via Esri’s Network Analyst extension for ArcMap 10.7. Connectivity of the line features was set to end-to-end, rather than to all nodes. Establishing the connectivity as all nodes would violate the topology; lines that cross would produce a node, creating shortcuts in the model that do not exist in the built environment. Care was taken to ensure that every line end connected to another line end; lines that connected to nodes in the middle of others would not be considered connected, again creating a false barrier in the model. Finally, turns were not modelled, the main cost factor was set to distance, and the network was processed.

Finally, the sheds were created. Based on the literature review, the selected travel speeds were 4.8km/h for the walksheds and PWC rollsheds, and 3.9km/h for the MWC rollsheds. However, the sheds were setup to run based on distance, not travel speed. Therefore, the travel speeds needed to be converted to metres per minute using Equation 4:

$$Eq. 4: \quad \frac{km}{hr} \times \frac{1000m}{km} \times \frac{hr}{60min}$$

Unimpeded, a pedestrian could travel 80 metres per minute in the walksheds and PWC rollsheds, and 65 metres per minute in the MWC rollsheds. Next, three starting locations were selected: student housing, the Welcome Centre and the bus loop. Three sheds were required for each starting point: a walkshed, PWC rollshed and an MWC rollshed, resulting in nine total sheds. To create a shed, the “New Service Area” option was selected. The user must load the starting facility and add point barriers/costs and line barriers/costs. Elevators were the first point cost added, since they were used in all nine sheds. Their additional cost was 160 metres for the walksheds and PWC rollsheds, and 130 metres for MWC rollsheds (two minutes of travel distance). However, the elevators placed on path junctions with three or more pathway splits did not function properly. In these special cases, an elevator was placed on each path segment around the junction and given a cost of one minute. Therefore, a two-minute impedance was added regardless of travel direction. The point barriers were then uploaded to the rollsheds; there were 295 total barriers between the steps, curb drops and pathway obstruction features. Lastly, the line costs were added: the step scaling for the walksheds, and the path costs values from equations 1 to 3 for the rollsheds. The line scaling cost function multiplied the path distance by the scaled cost. Essentially, a scaled cost of one resulted in no speed reduction, a scaled cost of two resulted in a travel speed that was half as fast, and a scaled cost of 0.5 would result in a travel speed that is twice as fast. All scale costs were of value one or greater.

Once the facility location and costs/barriers were loaded the sheds were solved. The line generation option was selected instead of polygon generation, and the first default break was set to 80 metres and 65 metres, respectively, for the walksheds/PWC rollsheds and MWC rollsheds. This resulted in a polyline network that represented the total traversable distance in one minute. The polyline was exported and saved in a geodatabase. Next, the traversable distance in three minutes was solved, and the resultant polyline was again exported and saved in an external database. This process was repeated at increments of two minutes, until the entire pedestrian network was traversed, or twenty-one minutes was reached. The polylines representing the time increments were loaded in another ArcMap document and shed visualizations were produced.

3.4.4 Producing Least-Cost Routes

Least-cost path routes were calculated between prominent VIU Nanaimo campus buildings to provide insight into the distance travelled and time exhausted by the three unique types of pedestrian. The routing was again performed with the Esri Network Analyst, using the same point and line costs/barriers. However, the routing required two facility locations to calculate the least cost path between them. Four routes with different start and end points were selected: building 370 to building 180, building 210 to building 356, building 305 to building 345 and building 200 to building 108. Each route was processed, and the resultant polylines were exported into an external geodatabase and visualized cartographically.

4. Results

4.1 Campus AM Map

The main campus map (Figure 4) and the student housing map (Figure 5) highlight the challenges of AM wayfinding on the VIU campus. Many accessible paths are concentrated near the centre of the campus, between buildings 205 and 315, orientated in the North-South direction; the perimeter of the campus generally has steep and very steep slopes (Figure 4). Notable areas where safe and barrier free travel is challenging includes the regions between

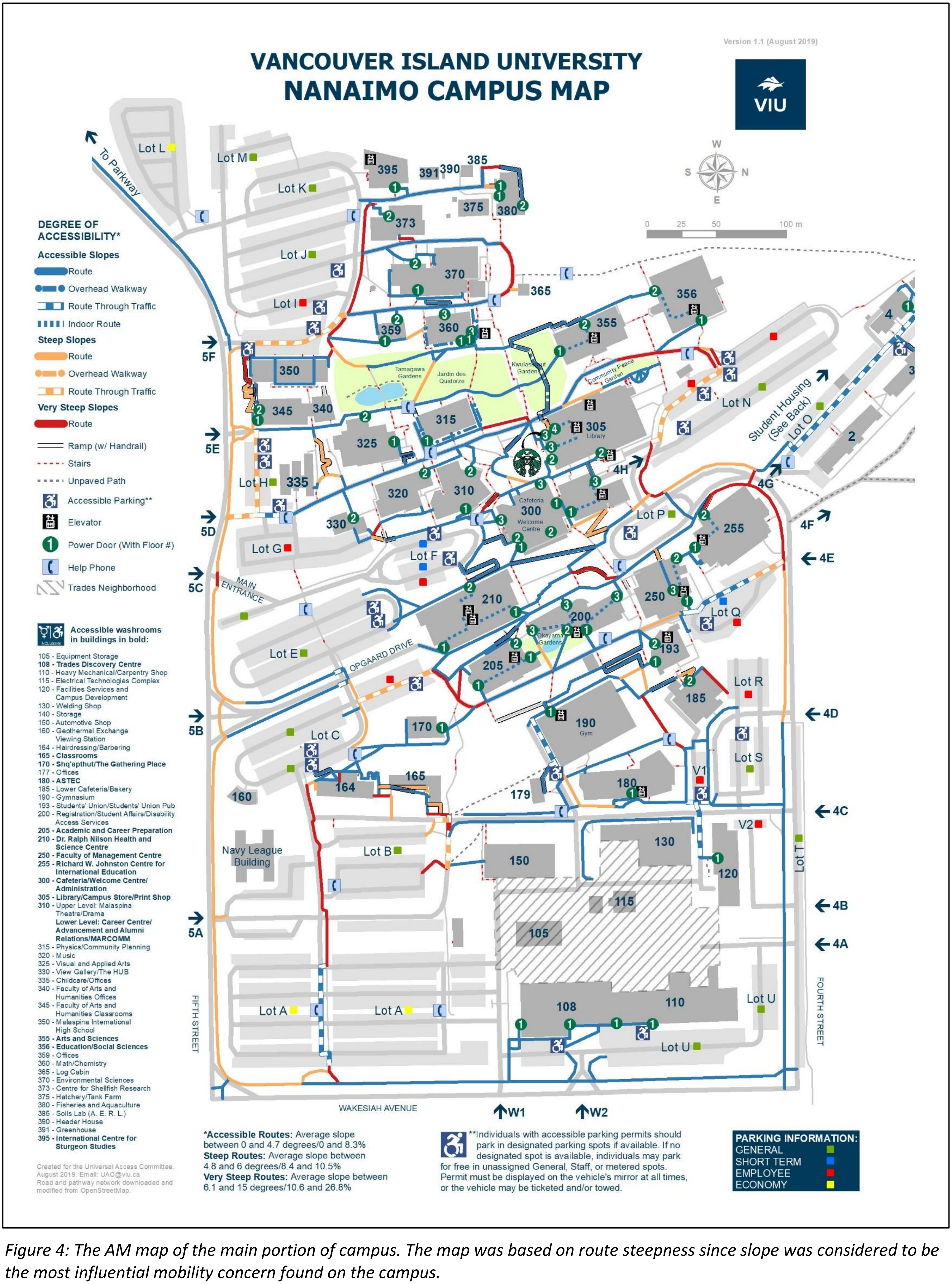

Figure 4: The AM map of the main portion of campus. The map was based on route steepness since slope was considered to be the most influential mobility concern found on the campus.

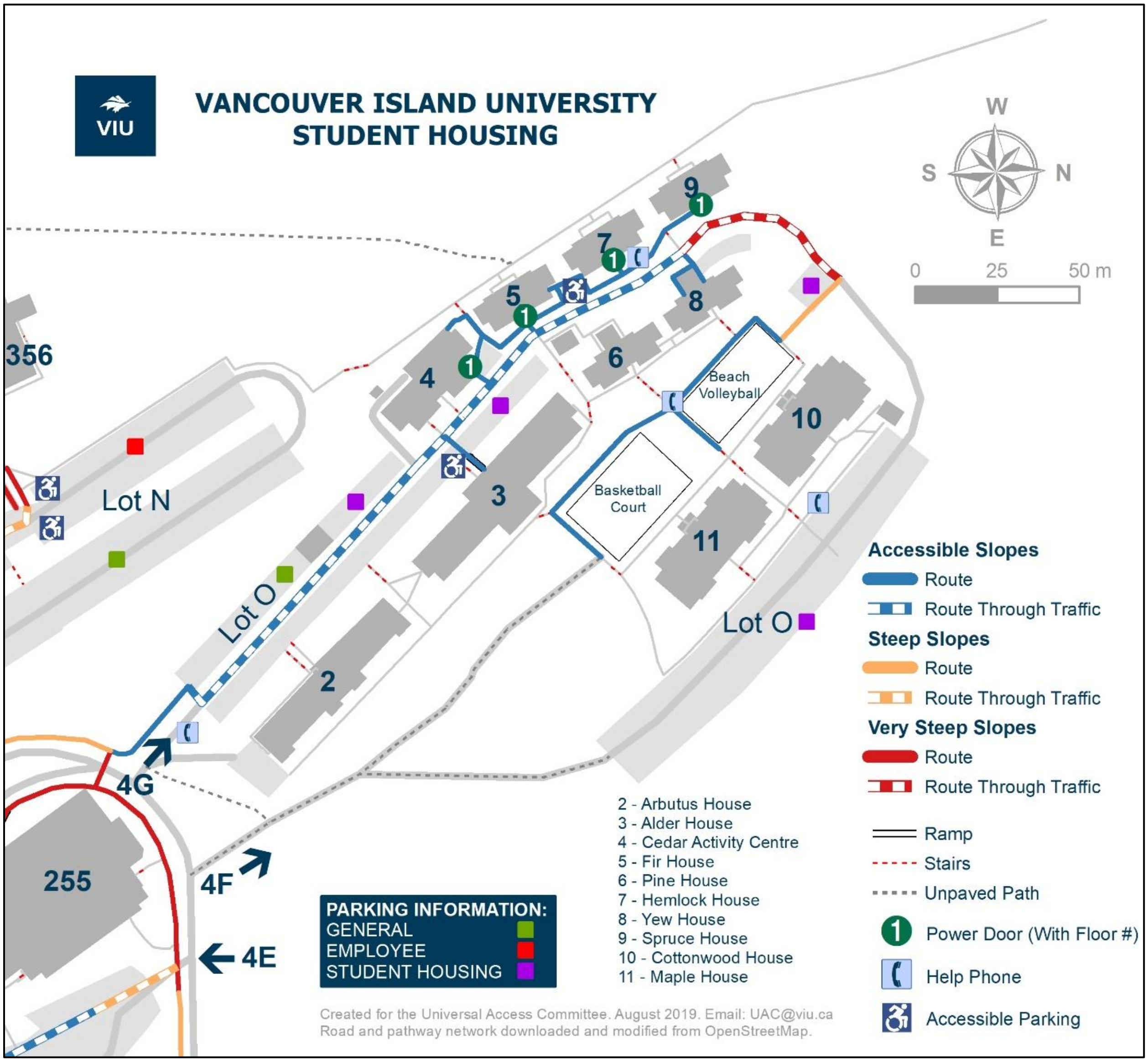

Figure 5: The student housing AM map. The majority of the routes in the area are through traffic.

building 255 and student housing, building 305 and Lot N and around building 335 up to building 395. These areas are dominated by long stretches of steep and very steep slopes that include some routes through traffic. Additionally, it is challenging to travel from the bottom of the campus to the top without navigating an interior route that requires elevator usage. However, many buildings lock once the school day is over; special permission is required to access them after hours. Furthermore, some of the elevators are unreliable and periodically malfunction. These issues may force individuals to traverse longer and steeper exterior paths.

AM in the student housing complex (Figure 5) is limited. The majority of the buildings can only be reached if a mobility limited individual navigates through traffic; others are completely inaccessible. Additionally, the beach volleyball and basketball courts are only attainable via a very steep route through traffic.

4.2 Service Area Analysis and Routing

The Welcome Centre (building 300) sheds start from a centered point on campus, slightly above the 200s level (Figure 6). All areas on campus can be reached in a nine-minute time period in the walkshed. All barrier-free pathways on campus are attainable within seventeen minutes in the PWC rollshed. The MWC rollshed does not reach the full extent within twenty-one minutes; traveling to the Fisheries and Aquaculture building (building 380), and the area East of the Trades Discovery Centre (building 108) require more time.

Figure 7 visualizes the sheds beginning from the bus loop. All pathways on campus are covered within an eleven-minute time frame in the walkshed. All barrier-free pathways are attainable within nineteen minutes based on the PWC rollshed. However, the MWC rollshed again shows unobtainable paths within the twenty-one-minute timeframe; the area West of the Math/Chemistry building (building 360) was not reached.

The student housing sheds started Northward compared to the others (Figure 8). The walkshed was complete, within a timeframe of thirteen minutes. The PWC shed did not arrive at the Fisheries and Aquaculture building, while the MWC shed did not reach accessible paths Southwest of the Physics building (building 356), nor accessible paths Southeast of the Trades Discovery Center.

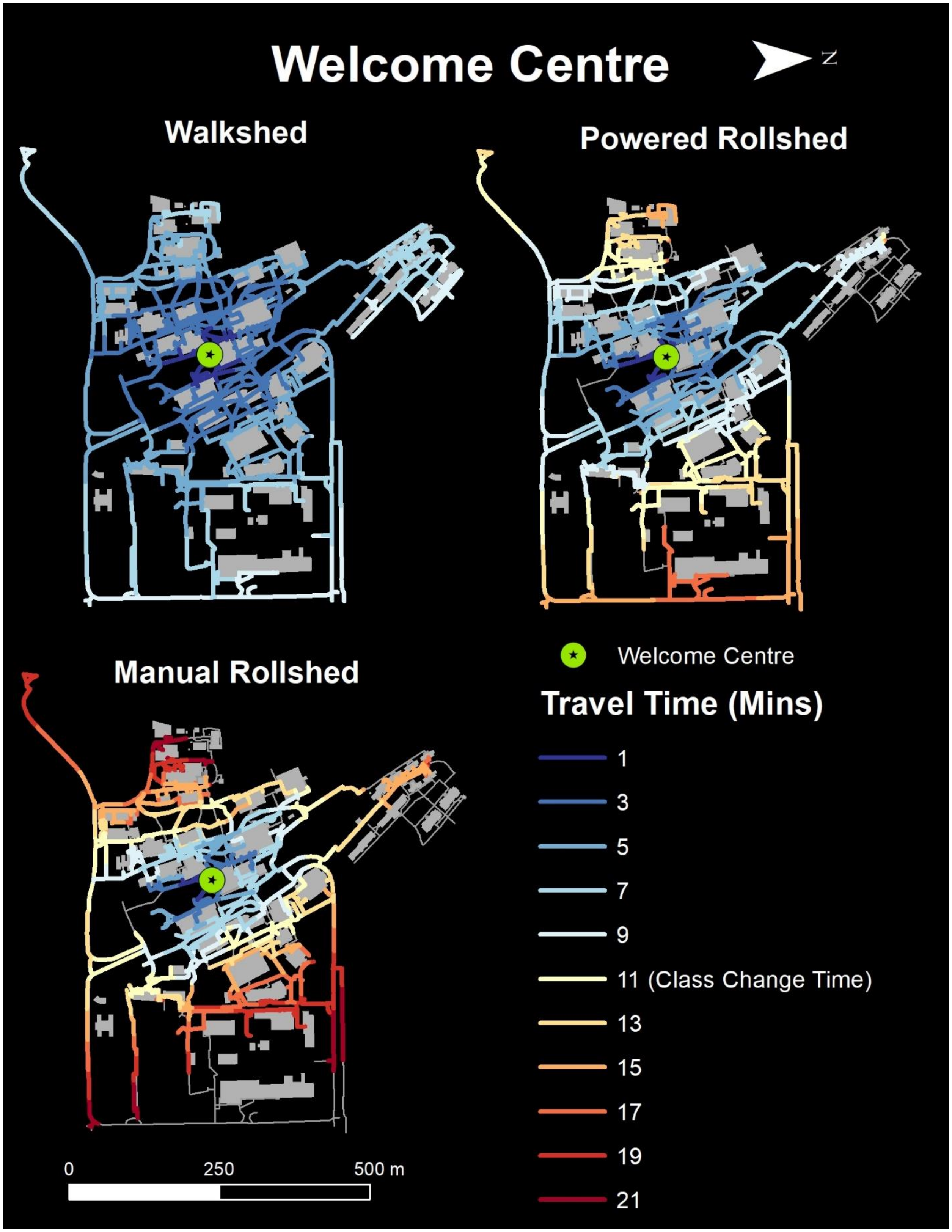

Figure 6: The sheds produced around the Welcome Centre. The distance covered over a span of one to twenty-one minutes is visualized for walking pedestrians, PWC users and MWC users.

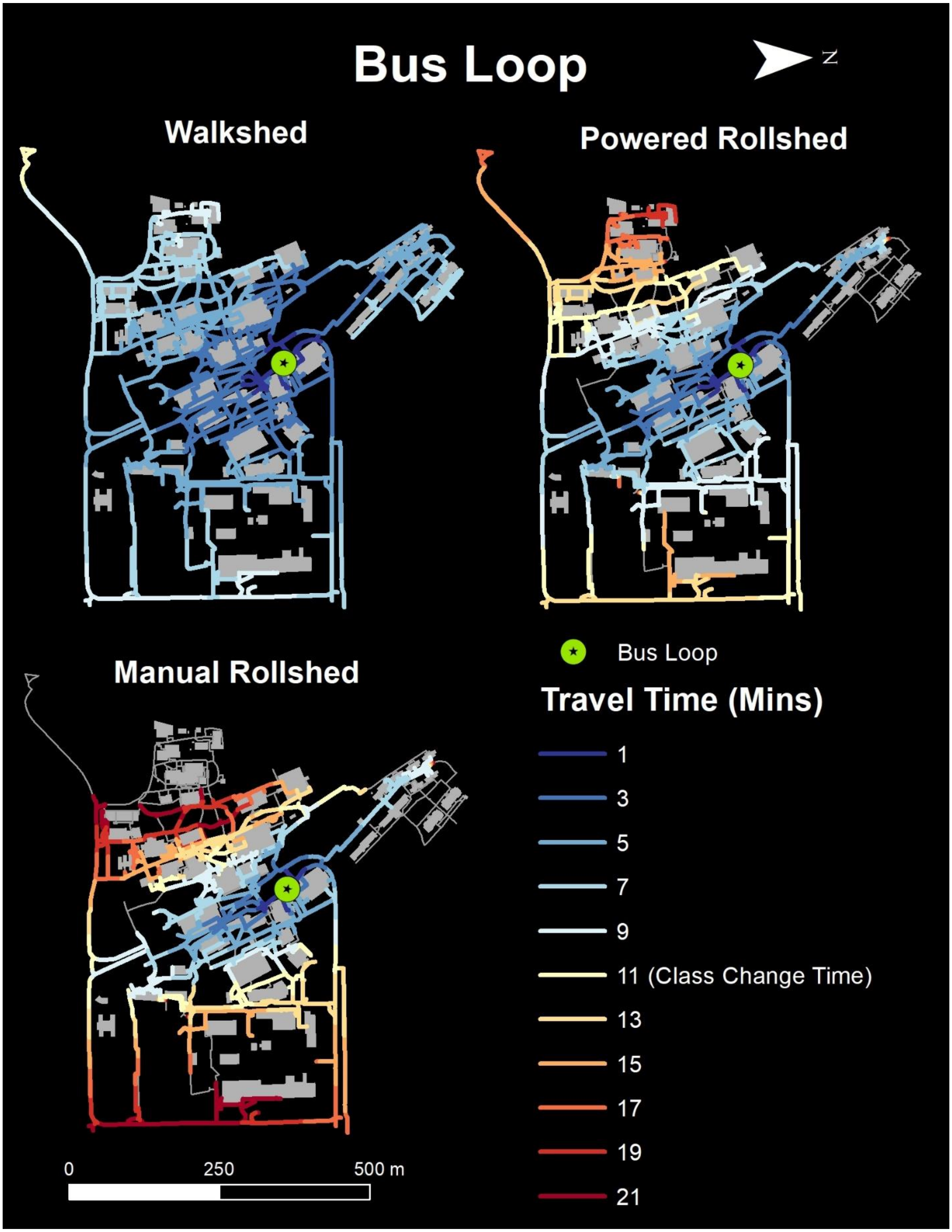

Figure 7: The sheds produced around the bus loop. The distance covered over a span of one to twenty-one minutes is visualized for walking pedestrians, PWC users and MWC users.

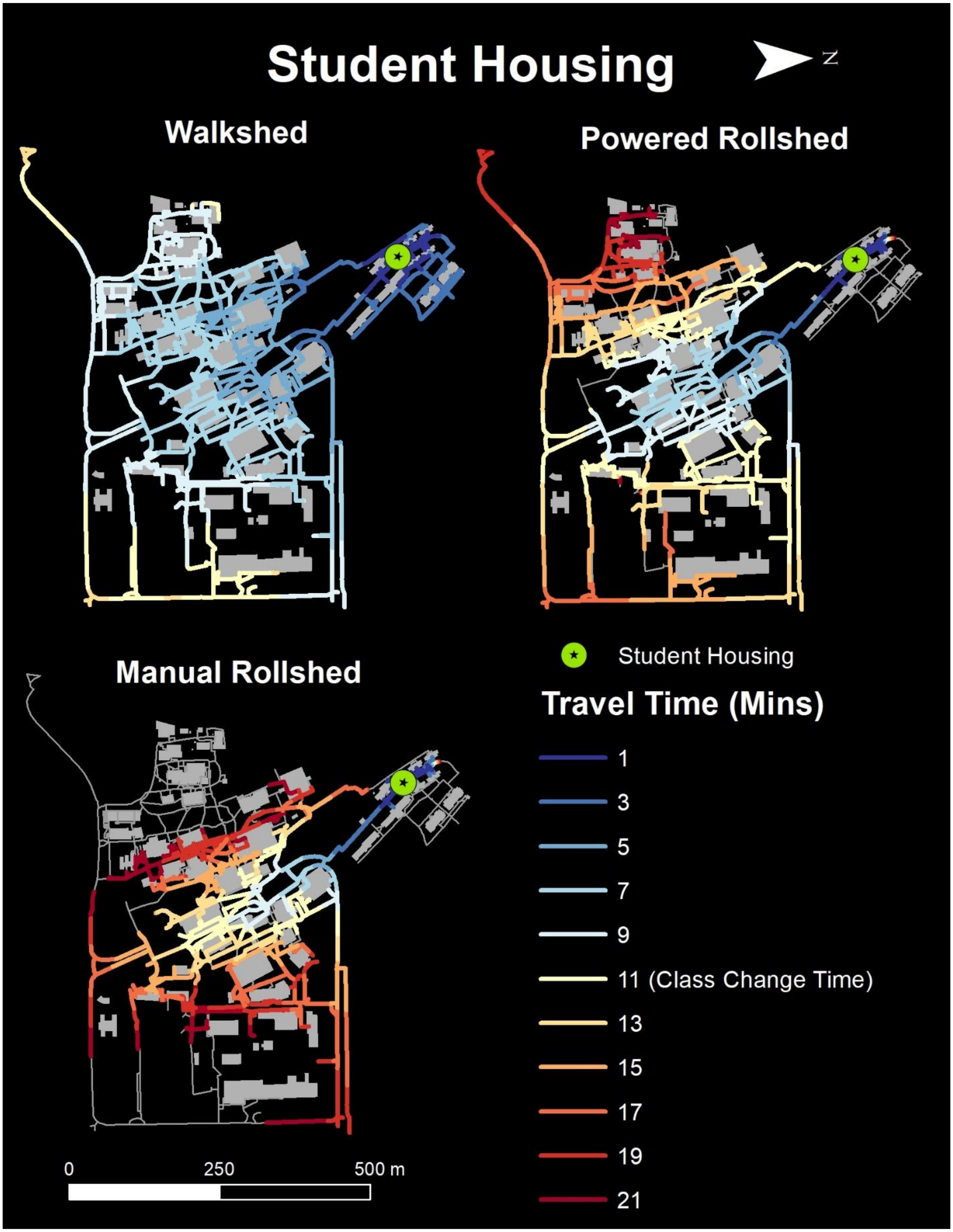

Figure 8: The sheds produced from student housing. The distance covered over a span of one to twenty-one minutes is visualized for walking pedestrians, PWC users and MWC users.

Notable trends and patterns are visible within the sheds. The walksheds extend in all directions in a uniform fashion, with similar reach up/down slope and perpendicular to slope. This creates a circular pattern. Contrarily, the rollsheds extend faster across the level portion of the campus (North-South), and slower up and down slope (East-West). This gives the rollsheds an elliptical shape, with the semi-minor and semi-major axes orientated up/down slope and perpendicular to slope, respectively.

Figure 9 is a larger cartographic scale version of the PWC student housing rollshed. There is one accessible route from the student housing complex to the main campus, because there are steps on the pathway to the West, rendering it inaccessible. Additionally, the pink circle highlights an area in the 300s level where the East-West travel of mobility-limited pedestrians is slowed by the multitude of steps, interior passages, elevators, and steep slopes.

Figure 9: A larger cartographic scale version of the PWC Student Housing rollshed, highlighting where bottlenecks exist within the VIU Nanaimo campus pedestrian network. The red circle locates the only accessible route leaving the student housing complex. The pink circle locates an area in the 300s, where East-West movement is bottlenecked by steps, steep slopes, interior passages and elevators.

Table 5: Distance and travel time spent navigating the least-cost routes for walking pedestrians, PWC users and MWC users.

	Walking		PWC		MWC	
	Distance (m)	Time (mins)	Distance (m)	Time (mins)	Distance (m)	Time (mins)
B370 to B180	693	9.64	1047	20.22	1047	35.75
B210 to B356	319	3.98	378	5.85	378	10.85
B305 to B345	268	3.35	288	4.34	288	6.91
B200 to B108	468	6.06	709	10.49	702	17.57
TOTAL	1748	23.03	2422	40.90	2415	71.08

The results of the least-cost paths routing are summarized in Table 5 and visualized in Figure 10. The length of the routes from largest to smallest for all three travel types was building 370 to 180, building 200 to 108, building 210 to 356 and building 305 to 345. The longest routes are between buildings on different campus levels; the shortest route connects two buildings on the same level. The wheelchair users would travel over an additional half kilometre compared to the walking pedestrians and have longer commute times. Notably, the

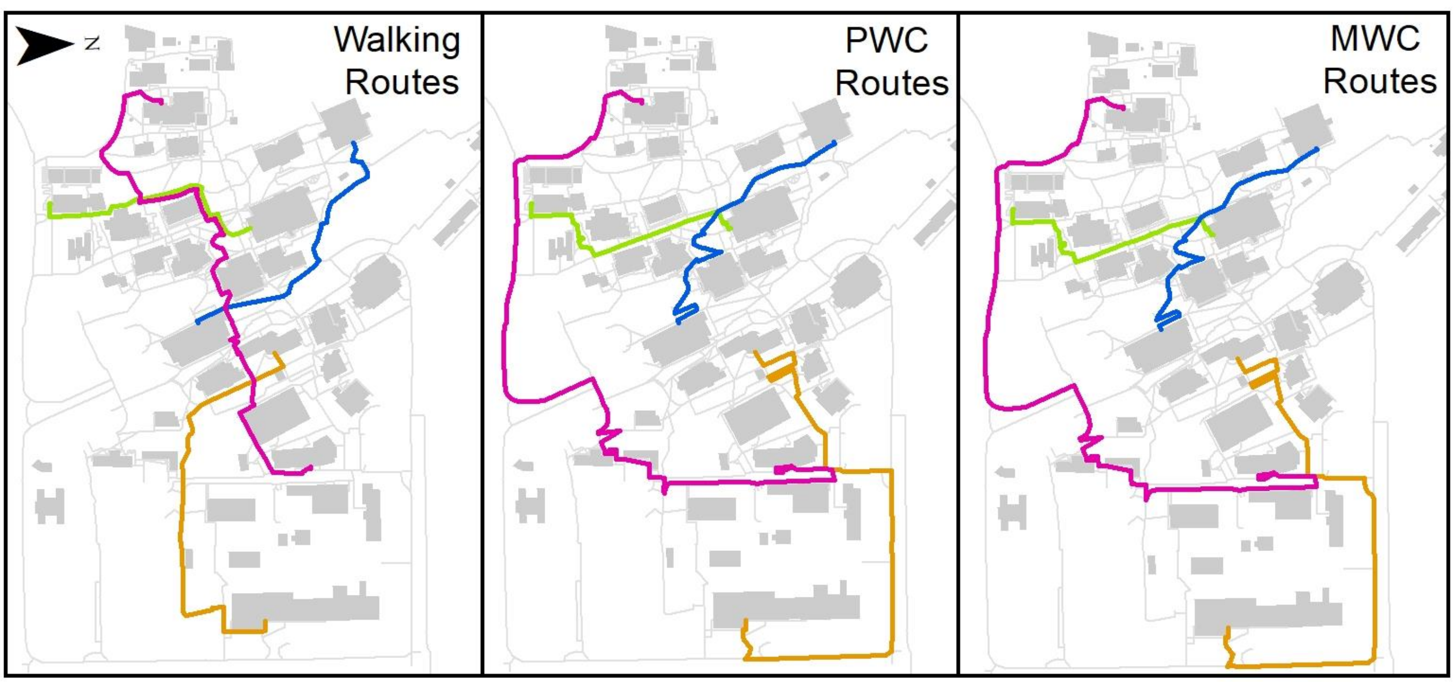

Figure 10: The walking, PWC and MWC least-cost path routes. Magenta: B370 to B180, Blue: B210 to B356, Green: B305 to B345, Orange: B200 to B108.

routes modeled for the PWC and MWC users are nearly identical. However, the travel time for the MWC users was longer; an MWC user could expect to spend approximately thirty additional minutes navigating the same routes as a PWC user.

5. Discussion

5.1 The Campus Map: Reception and Upkeep

The project's first objective was delivering a high-quality AM map that aids the wayfinding and navigation of VIU's Nanaimo campus mobility-limited patrons. The map was officially released during RockVIU 2019, VIU's welcome back and student orientation event held during the first week of September. The campus Starbucks sponsored the map, covering the cost of the 5000-copy print run. The AM map was handed out to students during the event and extra copies were stocked at information kiosks spread around the campus. Additionally, it was recommended that VIU host the map on the web where individuals could easily access it; institutions need to make AM wayfinding maps accessible, or else they will not serve their intended purpose. The AM map is available on VIU's campus map web page and on the Universal Access Committee (UAC) subpage. Furthermore, it is vital to provide support and information for users that may find the map challenging to read. The map was simplified to promote a straightforward user experience. However, it still contains a substantial amount of cartographic information; the UAC website should be updated to include best practices for effective map usage and route planning.

Currently, there are no statistics that prove the AM map effectively aids individuals living with mobility disabilities navigate the campus. However, the VIU Disability Access Services (DAS) mentioned that questions regarding accessibility routing have decreased significantly since the release of the map (M. Stasiuk, personal communication, January 13, 2020). This is an encouraging indication that the map is helping as planned and has reduced the workload of the VIU DAS.

It is required that the AM mapping methodology be reproduceable to be effectively employed on other post-secondary institution campuses. Unfortunately, the step-by-step methodology presented above is not perfectly reproduceable for every locality. However, the general workflow can be modelled. First, the typology must include every potential barrier and aid to mobility of the site. Every effort was made to build a universally useable AM data typology; however, new campuses may present new aids and barriers that were not identified on the VIU campus. If this is the case, the typology must be modified to ensure complete feature collection. Additionally, it is essential that the aids and barriers to mobility are consistently and impartially measured by all members of the mapping team.

The visualization of the dataset is a less intuitive process. Pathway slope was the primary access concern on the VIU campus; hence, the map was centered around the categorization of pedestrian path slopes, with other access aids and barriers added to bolster wayfinding information. This procedure is reproduceable: identify the largest accessibility concern/concerns and focus the wayfinding map to help individuals cope with it/them. Nevertheless, each institutions' map will be unique. Producing an AM wayfinding map by categorizing pathway steepness worked for the University of Arkansas campus (Raiees-Dana, 2012), but the ranges for the slope categories were different from the VIU AM map. It is important to select slope ranges that best represent the general steepness of an area. Furthermore, pathway slope is not a universal accessibility concern. An AM wayfinding map based on campus pathway steepness would not be useful for the University of Calgary campus, where pathways are generally flat (Hayat and Fast, 2019). An access wayfinding map for the University of Calgary could potentially focus on pathway size and quality (width or surface type for example).

Once the map was published it was immediately out of date. Continued upkeep of the AM map is crucial. VIU is currently upgrading ramps, installing power door operators and has further plans to improve the accessibility of the Nanaimo campus. Therefore, the data collection must remain open-ended and the campus map needs to be updated consistently to reflect these changes in the database. This will ensure that the map does not become obsolete. Currently, VIU facilities management does not have any GIS support within their department. Ideally, facilities management will in time incorporate GIS into their department and ensure the integrity and quality of the map is upheld.

Additionally, further work is required to support individuals living with other forms of disabilities. For example, haptic wayfinding information for the visually impaired, mapping for those living with acoustic disabilities, and support for those that are highly sensitive to intense smells.

5.2 The Shape of the Sheds: Class Change Times are Too Short

The sheds provide valuable AM information about the VIU Nanaimo campus, and their shapes show that the routes for mobility-limited individuals requiring stair-free movement are significantly longer and more complex than those of walking pedestrians. Therefore, adding navigation and wayfinding support for these individuals is of the utmost importance.

The pedestrian dispersion of each time increment in the rollsheds is longer North-South across the campus, compared to the East-West direction. This coincides with the slope of the campus, and therefore as expected, the pathway steepness of the campus greatly hinders the movement of mobility-limited individuals. Walking pedestrians have numerous options to move up and down the campus since they can navigate stairs. Pedestrians using wheelchairs or walking pedestrians living with mobility limitations do not have this luxury. Many of the stair-free pathways between campus levels are steep, limiting their usefulness. Mobility-limited users must use indoor passages and elevators, and the sparse, flat, safe routes to climb up or down elevation. This produces bottlenecks within the pedestrian network. Figure 9 shows that there is only one barrier-free pathway from the student housing complex to the main body of the campus. The student housing complex is directly East of the 300s level and building 356; however, a mobility-limited pedestrian must navigate a circuitous route through the 200s lasting anywhere from thirteen to nineteen minutes to reach building 356. A walking pedestrian can climb the stairs to the West of student housing and reach building 356 in approximately four minutes. Evidently, this bottleneck between student housing and the main campus body massively restricts the flow of the rollsheds. A ramp running parallel to the previously mentioned staircase would provide direct access to the 300s, and lower travel time of mobility-limited users. Other bottlenecks are visible in the 300s in all six rollsheds. Access across the gardens is limited; a wheelchair user would be required to take an indoor route, or the ramps and sidewalk on the South edge of campus. A walking pedestrian can navigate the large staircase running centrally East-West along the majority of the campus, reducing their travel time.

Students enrolled at the VIU Nanaimo campus have eleven minutes to travel to back to back classes. Additionally, classes can be scheduled in any building on the campus, from the 100s to the 300s. Table 5 gave the travel time for walking pedestrians, PWC users and MWC users for four potential routes during a class change. The walking pedestrians are estimated to arrive on time in each scenario, even from building 370 to building 180, a route that crosses all three campus levels. PWC users would arrive late in this scenario, needing an additional ten minutes to travel. PWC users would also be challenged to travel between buildings 200 and 108 on time, since they would only have thirty seconds of contingency time. They would not be able to briefly chat with their professor or colleagues and would need to have all of their material quickly packed for transport. Lastly, the routing model predicts that MWC users would have the longest day on campus. They would need thirty-five minutes to travel from building 370 to building 180, over three times the length of the class change period. They would also be late traveling from building 200 to building 108 and would have to rush to get from building 210 to building 356 on time. The only class change an MWC user could comfortably navigate is from building 305 to building 345, since the pathway between the buildings is generally flat and short.

The class change times are ableist. Eleven minutes does not provide a mobility-limited student sufficient time to comfortably reach the majority of their classes. However, it is unlikely that a university would extend the class change time; alternative options would need to be explored. First, the VIU Nanaimo campus should aim to eliminate bottlenecks and open up the full extent of their pedestrian network to all students and staff. Building ramps, smoothing slopes and adding exterior elevators are all options. However, fixing AM issues in the built environment is expensive. Solutions to the short class change time may not require the demolition of AM barriers or the construction of AM aids (although this would be ideal). VIU has discussed the idea of an AM shuttle bus; a shuttle service would transport mobility-limited students to their classes, ensuring they reach them on time. Nonetheless, conversations surrounding the implementation of a shuttle system are still in the preliminary phase. Another option is to increase the number of transit stops on the Nanaimo campus. Currently, there is a single bus stop, located in the 200s level. Adding a bus stop on the 100s and 300s campus levels allows students to plan their routes accordingly from three different elevations, and potentially limit the time and effort they spend climbing or descending the campus. Lastly, change could come from the administration side of student services. Administration could schedule the classes of mobility-limited individuals closer together or avoid scheduling classes back to back. Evidently, this is challenging considering the complexities that already dictate schedule making, but it is a strategy that should be investigated, nonetheless.

6. Conclusion

The objective of the project was to create a high quality and informative campus AM map for the students, staff and visitors of the VIU Nanaimo campus, while simultaneously providing information to facilities and administration to help plan future AM infrastructure changes and accommodations. The map was well-received by students and administration and is currently making wayfinding easier for patrons of the campus. Unfortunately, it is not a perfectly reproduceable methodology, and therefore alternative steps may be required to achieve similar success on other campuses. The rollshed analysis identified pedestrian bottlenecks and inaccessible areas, which should help the VIU Nanaimo campus develop a future strategy to promote easier access and navigation for mobility-limited individuals.

Students should not be forced out of educational opportunities due to physiological differences. It is vital that post-secondary institutions invest in providing AM information to students, mitigating barriers that would otherwise prohibit a mobility-limited student from achieving a higher education. However, improving the AM of all individuals is an endless process that continuously requires maintenance and constantly presents new challenges; institutions must remain vigilant and ensure that AM is an important consideration in their campus master plan.

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8. Appendices

Appendix A: AM Maps and Canadian Universities

Table A1: A list of accredited Canadian Universities and their types of campus maps, as of January 2020.

NAME	Static Map (No Access)	Static Map (Some Access)	Static Map (Dedicated to Access)	Web Map (No Access)	Web Map (Some Access)	Web Map (Dedicate to Access)
Alberta						
Athabasca University	0	0	0	0	0	0
Concordia University of Edmonton	0	0	0	1	0	0
MacEwan University	1	0	0	1	0	0
Mount Royal University	0	1	0	1	0	0
The King's University	0	0	0	1	0	0
University of Alberta	1	0	0	0	1	0
University of Calgary	1	0	0	1	0	0
University of Lethbridge	0	1	0	1	0	0
British Columbia						
Emily Carr University of Art + Design	1	0	0	0	0	0
Kwantlen Polytechnic University	1	1	0	1	1	0
Royal Roads University	0	1	0	0	1	0
Simon Fraser University	1	0	0	1	1	0
The University of British Columbia	1	0	0	1	0	0
Thompson Rivers University	1	0	0	1	0	0
Trinity Western University	1	0	0	0	0	0
University of Northern British Columbia	1	0	0	1	0	0
University of the Fraser Valley	0	1	0	1	0	0
University of Victoria	1	1	1	1	0	0
Vancouver Island University	1	0	1	1	0	0
Manitoba						
Brandon University	0	1	0	0	0	0
Canadian Mennonite University	1	1	0	1	0	0
St. Paul's College	0	0	0	0	0	0
The University of Winnipeg	1	1	1	0	0	0
University of Manitoba	0	1	0	1	0	0
Université de Saint-Boniface	1	0	0	0	0	0
New Brunswick						
Mount Allison University	1	0	0	0	1	0
St. Thomas University	1	0	0	1	0	0
University of New Brunswick	0	1	0	0	1	0
Université de Moncton	1	0	0	1	0	0

Newfoundland and Labrador						
Memorial University of Newfoundland	1	0	0	0	1	0
Nova Scotia						
Acadia University	0	1	0	1	0	0
Cape Breton University	1	0	0	0	0	0
Dalhousie University	1	0	1	1	0	0
Mount Saint Vincent University	0	1	1	1	0	0
NSCAD University	1	0	0	0	0	0
Saint Mary's University	1	0	0	0	0	0
St. Francis Xavier University	1	0	0	0	0	0
University of King's College	1	0	0	1	0	0
Université Sainte-Anne	1	0	0	0	0	0
Ontario						
Algoma University	1	0	0	0	0	0
Brescia University College	0	1	0	0	0	0
Brock University	1	1	0	0	1	0
Carleton University	1	1	0	1	0	0
Huron University College	1	0	0	0	0	0
King's University College at Western University	1	1	1	0	0	0
Lakehead University	0	1	1	1	0	0
Laurentian University	1	0	0	0	0	0
McMaster University	0	1	1	0	0	0
Nipissing University	0	1	0	0	1	0
OCAD University	1	0	0	0	0	0
Ontario Tech University	0	1	0	0	1	0
Queen's University	0	1	1	0	1	0
Redeemer University College	1	1	0	0	0	0
Royal Military College of Canada	1	0	0	0	0	0
Ryerson University	1	0	0	0	1	0
St. Jerome's University	1	0	0	0	0	0
Trent University	1	0	0	0	1	0
University of Guelph	0	1	0	0	1	0
University of Ottawa	1	1	1	0	1	0
University of St. Michael's College	0	1	0	0	0	0
University of Sudbury	1	0	0	1	0	0
University of Toronto	1	1	0	0	1	0
University of Trinity College	0	0	0	1	0	0
University of Waterloo	0	1	0	0	1	0
University of Windsor	0	1	0	0	1	0
Victoria University	0	1	0	1	0	0
Western University	0	1	1	1	0	0

Wilfrid Laurier University	0	0	1	1	1	
York University	0	1	1	0	1	0
Prince Edward Island						
University of Prince Edward Island	0	1	0	0	0	0
Quebec						
Bishop's University	1	0	0	1	0	0
Concordia University	0	1	0	0	1	0
Institut national de la recherche scientifique	0	0	0	0	0	0
McGill University	0	1	1	1	0	0
Polytechnique Montréal	1	0	0	0	0	0
Université de Montréal	1	0	0	0	1	0
Université de Sherbrooke	0	1	0	0	1	0
Université du Québec en Abitibi-Témiscamingue	0	0	0	0	0	0
Université du Québec en Outaouais	1	0	0	0	0	0
Université du Québec à Chicoutimi	1	0	0	0	0	0
Université du Québec à Montréal	1	0	0	0	1	0
Université du Québec à Rimouski	0	1	0	0	0	0
Université du Québec à Trois-Rivières	0	1	0	0	1	0
Université Laval	1	0	0	1	0	0
Université TÉLUQ	0	0	0	0	0	0
École de technologie supérieure	0	0	0	0	0	0
École des Hautes Etudes Commerciales (HEC)	1	0	0	0	0	0
École nationale d'administration publique	1	0	0	0	0	0
Saskatchewan						
Campion College	0	0	0	0	0	0
First Nations University of Canada	0	0	0	0	0	0
Luther College	1	0	0	1	0	0
St. Thomas More College	0	0	0	0	0	0
University of Regina	0	1	0	1	0	0
University of Saskatchewan	0	1	0	1	0	0
TOTALS						
Count:	**51**	**40**	**14**	**35**	**25**	**0**
Percentages:	**54.3%**	**42.6%**	**14.9%**	**37.2%**	**26.6%**	**0.0%**

Appendix B: Data Dictionary - Accessible Mobility Typology*

**Derived from the 2010 ADA Standards for Accessible Design (ADA, 2010), the RHF Accessibility Certification Ratings Professional Handbook (RHF, 2018) and the City of Calgary Access Design Standards (City of Calgary, 2016).*

Point Feature: **Level Change:** *def.* A significant change in the level of a footpath (trail or pedestrian pathway). Only recorded if greater than 2.5 centimetres.
Examples include missing bollards, pathway cracks/holes, pathway joints, tree roots, raised/lowered pathways.

Attributes:

- **Type:** (Choice/Other (Refer to notes)) *def.* The type of level change; see examples above.
- **Pedestrian pathway clear space:** (m) *def.* The effective width of the pedestrian pathway.
- **Height:** (cm) *def.* The height of the level change measured from the ground up/ground down.
- **Width:** (cm) *def.* The measurement of the level change along the minor axis. Not always an applicable measurement.
- **Length:** (cm) *def.* The measurement of the level change along the major axis.
- **Notes**

Point Feature: **Metal Cover:** *def.* A cover made from metal that is embedded in a pedestrian pathway.
Examples include storm-drain grates, manhole covers, tree grates, electrical grates.

Attributes:

- **Type:** (Grate/Man-Hole Cover/Other (refer to notes)) def. The metal cover classification.
- **Width:** (cm) *def.* The measurement of the metal cover along the minor axis.
- **Length:** (cm) *def.* The measurement of the metal cover along the major axis.
- **Openings width:** (cm) *def.* The distance between the openings (grates/holes) on the surface of the metal cover.
- **Perpendicular to pedestrian pathway:** (Y/N/N-A) *def.* Are the openings perpendicular to the primary path of travel on the pedestrian pathway?
- **Flush to ground:** (Y/N) *def.* Whether the metal cover is level with the ground surface.
- **Height:** (cm) *def.* If not flush with ground, the height of the metal cover.
- **Notes**

Point Feature: **Curb Cut:** *def.* A small ramp built into a pedestrian pathway that allows a wheelchair user to navigate a curb.
Examples include let-downs to pedestrian crosswalks, let-downs to accessible parking stalls.

Attributes:

- **Width:** (m) *def.* The measurement of the curb cut from side to side. It is measured along the portion that is flush (or closest to flush) to the lower elevation.
- **Length:** (m) *def.* The measurement of the curb cut end to end, or from the top platform to the bottom platform.
- **Running slope:** (degrees) *def.* The measurement of the curb cut incline parallel to the primary path of travel (along the length).
- **Cross slope:** (degrees) *def.* The measurement of the curb cut incline perpendicular to the primary path of travel (across the width).

- **Texture contrast:** (Y/N) *def*. Whether the top of the curb cut is easily distinguishable from the pedestrian pathway via texture.
- **Marked:** (Y/Faded/N/N-A) *def.* When crossing a street or entering a parking lot, a curb cut needs to be marked. Usually via paint (ex. zebra-striped crosswalks, marked zones following a curb cut leading to an accessible parking stall).
- **Landing pad size:** (Y/< Width/< Length/< Both) *def.* The landing pad (area on the pathway behind the curb cut) size is in accordance with the recommendations from the RHF. The width cannot be narrower than the width of the curb cut, and the length needs to be at least 1.5 m.
- **Perpendicular to path:** (Y/N/N-A) *def.* Whether the curb cut is aligned perpendicular to the primary direction of travel.
- **Contained within markings:** (Y/N/N-A) *def.* Whether the curb cut is contained wholly within the markings located down from the incline (if applicable).
- **Projects into vehicle area:** (Y/N) *def.* Whether the curb cut projects into a road, parking space, parking access aisle, and there is no marked pedestrian area (painted crosswalk, etc.).
- **Flared sides:** (Y/N) *def.* Side-angle transition from top of pathway to main running slope, parallel to the major-axis of the pathway.
- **Flared side slope:** (degrees) *def.* The long axis measurement of the flared side slope.
- **Stub-toe:** (Yes/No) *def.* Whether the curb cut let down is flush to the ground.
- **Stub-toe height:** (cm) *def.* The height of the stub toe curb, if applicable.
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the surface of the curb cut.
- **Notes**

Point Feature: **Curb Drop:** *def.* A point along a pathway where a curb cut/ramp would be required to facilitate the travel of small elevation changes, i.e. wherever an exterior barrier-free path of travel encounters a curb (City of Calgary, 2016).
Example: a curb in-line with a pedestrian street crossing.

Attributes:
- **Marked:** (Y/Faded/N/N-A) *def.* When crossing a street or entering a parking lot, a curb needs to be marked. Usually via paint (ex. zebra-striped crosswalks, marked zones following a curb leading to an accessible parking stall).
- **Perpendicular to path:** (Y/N/N-A) *def.* Whether the curb drop is aligned perpendicular to the primary path of travel.
- **Contained within markings:** (Y/N/N-A) *def.* Whether the curb drop is contained wholly within the markings (if applicable).
- **Projects into vehicle area:** (Y/N/N-A) *def.* Whether the curb drop projects into a road, parking space, parking access aisle.
- **Notes**

Point Feature: **Door:** *def.* A moveable barrier that opens to facilitate entering and exiting from a structure.
Examples include hinged manual doors, automatic sliding doors, revolving doors.

Attributes:
- **Type:** (Entrance/Exit/Both/Unknown) *def.* The type of access allowed through the door.

- **Access:** (Unlocked/Locked) *def.* Whether a door is locked or unlocked (accessible to the general public) during the day.
- **Width:** (cm) *def.* The measurement of the door frame along the minor axis, from side to side.
- **Opener:** (Automatic/Push Button/Manual) *def.* How the door opens; either automatically (sensor), with a push button operator or via manual effort.
- **Handle:** (Knob/Lever/Bar/None/Other (Refer to notes)) *def.* The type of exterior door handle.
- **Leads to interior stairs only:** (Y/N) *def.* Does the doorway lead to an interior staircase, with no other accessible routes as options?
- **Leads to exterior stairs only:** (Y/N) *def.* Does the doorway lead to an exterior staircase, with no other accessible routes as options?
- **Leads to manual doors:** (Y/N) *def.* Does the doorway lead to additional manual doors?
- **Clear space:** (cm) *def.* The amount of usable space between the door (including door handle) and the open-door frame.
- **Lip:** (cm) *def.* The height between the ground and the doorframe threshold.
- **Notes**

Point Feature: **Campus Map:** *def.* A cartographic image of the campus that helps one situate themselves. Additionally, they provide a general understanding of the campus layout.
An example would include a sign with a picture of the campus map and information about the buildings.

Attributes:

- **Height bottom:** (m) *def.* The distance to the bottom of the sign from the ground.
- **Height top:** (m) *def.* The distance to the top of the sign from the ground.
- **Size:** (m * m) *def.* The width of the sign by the length of the sign.
- **Sign distance:** (m) *def.* Straight-on distance from the edge of a pathway to the sign.
- **Map character size:** (mm) *def.* The measurement of the characters embedded in the map from the bottom to the top.
- **Wayfinding character size:** (mm) *def.* The measurement of the ancillary information characters (characters not included in the map body) from the bottom to the top.
- **Approachable and readable:** (Y/N) *def.* Whether one can get close enough to the sign to make sense of its information. Some signs may be blocked by curbs, elevated too high, or placed on uneven ground, for example.
- **Glare-free surface:** (Y/N) *def.* Indicates whether the surface of the sign is free of glare.
- **Notes**

Point Feature: **Accessible Parking Stall:** *def.* A parking stall that has been marked as accessible.
These accessible parking stalls are typically marked with paint or signs and should be found close to building entrances.

Attributes:

- **Width:** (m) *def.* The measurement of the parking stall along the minor axis.
- **Adjacent to access aisle:** (Y/N) *def.* Indicates whether the stall is adjacent to a safe access aisle that permits the offloading/loading of pedestrians from/into a vehicle.
- **Total width:** (m) *def.* The total useable width of the parking stall, potentially including the width of the access aisle.
- **Distance to entrance:** (m) *def.* Distance to the nearest barrier-free accessible building entrance.

- **Adjacent to curb cut/ramp:** (Y/N/N-A) *def.* Indicates whether the stall is adjacent to a curb ramp that would allow an individual to access a pedestrian area.
- **Signage:** (Stall/Sign/Both) *def.* Indicates whether the stall has been marked accessible by paint on the stall surface, by a sign in front of the stall, or both.
- **Slope:** (degrees) *def.* The maximum slope of the parking stall measured in any direction.
- **Notes**

Point Feature: **Pay Machine:** *def.* Any device that takes payment for a feature or a service.
Examples include parking pay machines, transit ticket machines.

Attributes:
- **Type:** (Choice) *def.* The type of pay machine, see examples above.
- **Height top:** (m) *def.* The height of the top of the operable parts from the ground.
- **Height bottom:** (m) *def.* The height of the bottom of the operable parts from the ground.
- **Notes**

Point Feature: **Elevator:** *def.* An enclosed automated device that lifts/lowers individuals from one level to another. May be an indoor or an exterior feature.
Elevators may be installed when a slope is too steep for the safe and comfortable negotiation from one level to another via ramps.

Attributes:
- **Type:** (Interior/Exterior) *def.* Whether the elevator is an interior or exterior feature.
- **Entrance width:** (m) *def.* The measurement of the elevator entrance along the minor axis, from side to side.
- **Width:** (m) *def.* The measurement of the elevator from side to side.
- **Length:** (m) *def.* The measurement of the elevator from end to end.
- **Operating Hours:** (hh:mm to hh:mm) *def.* The time that the elevator is operational each day.
- **Access to all floors:** (Y/N) *def.* Indicates whether the elevator can access all the floors within the building.
- **Handrails:** (Y/N) *def.* Indicates whether the elevator has interior handrails.
- **Handrail type:** (Round/Oval/Rectangular/Squared/Flat/Other (refer to notes)) *def.* The shape of the handrail.
- **Notes**

Point Feature: **Tactile Indicator:** *def.* Raised strips of material with tactile markings that indicate the beginning of staircases, ramps, escalators, etc.
They are commonly yellow and consist of circular raised bumps.

Attributes:
- **Indicates:** (Choice) *def.* The feature adjacent to the tactile indicator.
- **Width:** (m) *def.* The measurement of the tactile indicator's minor axis.
- **Length:** (m) *def.* The measurement of the tactile indicator's major axis.
- **Notes**

Point Feature: **Path Barrier:** *def.* Any above ground feature that could obstruct travel by reducing the usable width of the pedestrian street below 1.5 m.

Examples include trash receptacles, trees, benches, newspaper stands, lamp posts, mailboxes, bus shelters, plants/pots.

Attributes:

- **Type:** (Choice/Other (refer to notes)) *def.* The object that is blocking/obstructing the path. See examples above.
- **Pedestrian pathway clear space:** (m) *def.* The effective width of the pedestrian pathway/trail taking the path barrier into account.
- **Length:** (m) *def.* The measurement of the obstruction parallel to the path of travel.
- **Width:** (m) *def.* The measurement of the obstruction perpendicular to the path of travel.
- **Notes**

Point Feature: **Assistance Phone Kiosk:** *def.* A pole/booth/feature that contains a phone connecting to security or a help line. Useful in the case of an emergency.
Assistance phone kiosks are common on campuses, and typically have some form of push button functionality that connects an individual with a help line.

Attributes:

- **Button/pad height:** (m) *def.* The height (to the middle) of the button/pad used to dial the phone from the ground.
- **Speaker height:** (m) *def.* The height (to the middle) of the speaker from the ground.
- **Notes**

Line Feature: **Problematic Pedestrian Pathway:** *def.* A paved/tiled/wood pathway used mainly or exclusively by pedestrian that hinders mobility in some fashion.
Examples include steep sidewalks along automobile roadways, paved foot paths in the campus interior that lack edge protection and narrow parking aisles dedicated to pedestrian travel.

Attributes:

- **Width:** (m) *def.* The measurement of the pedestrian pathway along the minor axis (side to side).
- **Length:** (m) *def.* The measurement of the pedestrian pathway along the major axis (end to end).
- **Shared use:** (Y/N) *def.* Shared access with vehicles (usually service vehicles, campus security).
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the surface of the pathway.
- **Passing spaces:** (One/Multiple/None/N-A) *def.* Areas where the pedestrian pathway widens to allow pedestrians to pass one another. Not applicable if the path has a width equal to or greater than 1.5 m.
- **Passing space interval:** (m): *def.* The distance between the passing spaces along the length of the pedestrian pathway. Not always applicable.
- **Edge protection:** (Both sides/One side/None/N-A) *def.* Protection from a sharp drop off may be required along some paths.
- **Average running slope:** (degrees) *def.* The measurement of the mean (or most consistent) pedestrian pathway slope parallel to the primary path of travel.
- **Maximum running slope:** (degrees) *def.* The measurement of the maximum pedestrian pathway slope parallel to the primary path of travel.
- **Average cross slope:** (degrees) *def.* The measurement of the mean (or most consistent) pedestrian pathway slope perpendicular to the primary path of travel.

- **Maximum cross slope:** (degrees) *def.* The measurement of the maximum pedestrian pathway slope perpendicular to the primary path of travel.
- **Notes**

Line Feature: **Trail:** *def.* A path of travel for pedestrians that is not paved/tiled.
Examples include hiking trails, desire lines, dirt routes that travel through campus.

Attributes:

- **Width:** (m) *def.* The measurement of the trail along the minor axis (side to side).
- **Length:** (m) *def.* The measurement of the trail along the major axis (end to end).
- **Shared use:** (Y/N) *def.* Shared access with vehicles (usually service vehicles, campus security).
- **Surface type:** (Choice/Other (refer to notes)) *def.* The material used to construct the surface of the trail. Examples include wood chips, dirt, gravel, river rock.
- **Passing spaces:** (One/Multiple/None/N-A) *def.* Areas where the trail widens to allow pedestrians to pass one another. Not applicable if the trail has a width equal to or greater than 1.5 m.
- **Passing space interval:** (m): *def.* The distance between the passing spaces along the length of the trail. Not always applicable.
- **Edge protection:** (Both sides/One side/None/N-A) *def.* Protection from a sharp drop off may be applicable along some trails.
- **Average running slope:** (degrees) *def.* The measurement of the mean (or most consistent) trail slope parallel to the primary path of travel.
- **Maximum running slope:** (degrees) *def.* The measurement of the maximum trail slope parallel to the primary path of travel.
- **Average cross slope:** (degrees) *def.* The measurement of the mean (or most consistent) trail slope perpendicular to the primary path of travel.
- **Maximum cross slope:** (degrees) *def.* The measurement of the maximum trail slope perpendicular to the primary path of travel.
- **Notes**

Line Feature: **Crosswalk:** *def.* A marked (usually by paint) pedestrian pathway across a vehicle lane (street/highway/parking lot).
Crosswalks are generally in between curb cuts and permit safer travel across roadways.

Attributes:

- **Width:** (m) *def.* The measurement of the crosswalk along the minor axis (side to side).
- **Length:** (m) *def.* The measurement of the crosswalk along the major axis (end to end).
- **Type:** (Uncontrolled/pedestrian controlled/major intersection (traffic light controlled)) *def.* The type of crosswalk, discussing the methods of pedestrian and automobile right-of-way.
- **Running slope**: (degrees) *def.* The measurement of the crosswalk slope parallel to the primary path of travel.
- **Cross slope:** (degrees) *def.* The measurement of the crosswalk slope perpendicular to the primary path of travel.
- **Curb cuts:** (Both/One/None/N-A) *def.* Indicates whether both sides of the crosswalk are accompanied by a curb cut.
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the surface of the crosswalk.

- **Marked:** (Y/Faded/N/N-A) *def.* Is the crosswalk distinguished from the street?
- **Notes**

Line Feature: **Curb Ramp:** *def.* A long ramp built along a pedestrian pathway.
Examples include long ramps along a passenger drop-off zone, long ramps along driveways.

Attributes:

- **Width:** (m) *def.* The measurement of the curb ramp from side to side. It is measured along the portion that is flush (or closest to flush) to the lower elevation.
- **Length:** (m) *def.* The measurement of the curb ramp from end to end, or from the top platform to the bottom platform.
- **Running slope:** (degrees) *def.* The measurement of the curb ramp incline parallel to the primary path of travel (along the length).
- **Cross slope:** (degrees) *def.* The measurement of the curb ramp incline perpendicular to the primary path of travel (across the width).
- **Texture contrast:** (Y/N) *def.* Whether the curb ramp is easily distinguishable from the pedestrian pathway via texture.
- **Marked:** (Y/N/N-A) *def.* When crossing a street or entering a parking lot, a curb ramp needs to be marked. Usually via paint (ex. zebra-striped crosswalks, marked zones following a curb ramp leading to an accessible parking stall).
- **Landing pad size:** (Y/< Width/< Length/< Both) *def.* The landing pad (area on the pathway behind the curb ramp) size is in accordance with the recommendations from the RHF. The width cannot be narrower than the width of the ramp, and the length needs to be at least 1.5 m.
- **Perpendicular to pathway:** (Y/N/N-A) *def.* Whether the curb ramp is aligned perpendicular to the primary direction of travel.
- **Contained within markings:** (Y/N/N-A) *def.* Whether the curb ramp is contained wholly within the markings located down from the incline (if applicable).
- **Projects into vehicle area:** (Y/N) *def.* Whether the curb ramp projects into a road, parking space, parking access aisle, and there is no paint marked pedestrian area (painted crosswalk, etc.).
- **Stub-toe:** (Y/N) *def.* Whether the curb ramp let down is flush to the ground.
- **Stub-toe height:** (cm) *def.* The height of the stub toe curb, if applicable.
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the curb ramp.
- **Notes**

Line Feature: **Steps:** *def.* A set of flat and continuously elevated surfaces at ninety-degree angles that facilitate movement from one level to another. Cannot be negotiated safely in a wheelchair.
Steps are typically found in front of elevated buildings or in hilled areas.

Attributes:

- **Width:** (m) *def.* The steps measurement from side to side.
- **Length:** (m) *def.* The total measurement of all steps, from end to end.
- **Handrails:** (Both/One/None) *def.* Indicates whether the steps have handrails on both sides, one sides or on neither of the sides.
- **Handrail type:** (Round/Oval/Rectangle/Squared/Flat/Other (refer to notes)) *def.* The shape of the handrail.

- **Handrail bump:** (Y/N/N-A) *def.* Whether the steps have tactile indicators on their handrails that inform persons' living with visual impairments.
- **Edge protection:** (Both sides/One side/None/N-A) *def.* Protection from a sharp drop-off may be applicable for some steps.
- **Curved/circular:** (Y/N) *def.* Indicates whether the steps curve or are circular.
- **Marked:** (Y/Faded/N) *def.* Indicates whether the tops of the individual steps (the stair nosing) have been marked (usually painted yellow, helps individuals who are visually impaired negotiate the staircase).
- **Rest areas:** (Y/N/N-A) *def.* Some larger steps may require rest areas.
- **Rest area interval:** (m) *def.* Distance between the rest areas.
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the surface of the steps.
- **Notes**

Line Feature: **Ramp:** *def.* Sloped feature that enables travel from one level to another. Alternative option to stairs for those living with a disability.
Commonly found in front of elevated buildings or hilled areas.

Attributes:

- **Width:** (m) *def.* The ramp measurement from side to side.
- **Length:** (m) *def.* The ramp measurement from end to end.
- **Average running slope:** (degrees) *def.* The measurement of the mean (or more consistent) ramp slope parallel to the primary path of travel.
- **Maximum running slope:** (degrees) *def.* The measurement of the maximum ramp slope parallel to the primary path of travel.
- **Average cross slope:** (degrees) *def.* The measurement of the mean (or more consistent) ramp slope perpendicular to the primary path of travel.
- **Maximum cross slope:** (degrees) *def.* The measurement of the maximum ramp slope perpendicular to the primary path of travel.
- **Handrails:** (Both/One/None) *def.* Indicates whether the ramp has handrails on both sides, one sides or on neither of the sides.
- **Handrail type:** (Round/Oval/Rectangle/Squared/Flat/Other (refer to notes)) *def.* The shape of the handrail.
- **Handrail bump:** (Y/N/N-A) *def.* Whether there are tactile indicators on the ramp handrails that inform persons' living with visual impairments.
- **Edge protection:** (Both sides/One side/None/N-A) *def.* Protection from a sharp drop-off may be applicable for some ramps.
- **Curved/circular:** (Y/N) *def.* Indicates whether the ramp curves or is circular.
- **Rest areas:** (Y/N/N-A) *def.* Some larger ramps may require rest areas for individuals.
- **Rest area interval:** (m) *def.* Distance between the rest areas.
- **Landing pad size:** (Y/< Width/< Length/< Both) *def.* The landing pad (area on the pathway behind the ramp) size is in accordance with the recommendations from the Rick Hansen Foundation. The width cannot be narrower than the width of the ramp, and the length needs to be at least 1.5 m.
- **Surface type:** (Concrete/paving tiles/asphalt/exposed aggregate/wood/other (refer to notes)) *def.* The material used to construct the surface of the ramp.
- **Notes**