Improving Walkability Based on Hedonic Qualities

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1. Abstract

Walkability is becoming a central theme in urban planning. This is happening for a variety of reasons, including public demand and the desire to reduce carbon emissions per capita. Health studies examining physical activity have found that walking and biking facilitate physical rehabilitation and mitigate modern chronic diseases, such as obesity, hypertension, and depression. Because walkability is closely related to the concepts of improved livability and sustainability, we want to create a tool to help designers enhance the walkability of cities.

Urban planners working on walking routes often like to have data to justify their design choices. So, we designed a tool that visualizes how different human factors vary along a route to validate and/or improve an urban planner's design choices. In comparison to existing walkability tools that emphasize utilitarian factors such as available destinations, our tool focuses on incorporating factors such as a person's perception of safety, areas of visual interest, and exposure to greenery. These factors are visualized by being plotted along a stacked area chart in the Grasshopper platform, where the x axis represents the distance along a path and the y axis represents the human factors. We hope our tool will help urban planners better justify their design choices and be applied in a user application like Google Maps or Apple Maps.

Keywords: walkability, urban planning, Grasshopper, hedonic enjoyment, human-centered design

2. Introduction

Walking has historically been the primary mode of transportation in urban parts of the United States. However, as the population started to grow during the 1950s, the rapid expansion of cities made walking less feasible. This, along with cars becoming more popular, led to a significant reduction in walking for daily activities. As urbanization increased and more people started to own cars, they moved out of cities and into the suburbs. This expansion pattern is known as urban sprawl, and it creates a lifestyle dependent on cars because daily destinations are more scattered (Glaeser & Kahn, 2004). From the 1950s until the 1970s, most urban planning focused on creating space for motorized transportation, especially highways to connect urban centers to the suburbs. Only with the 1973 oil crisis and the expansion of high-rise buildings did urban developers begin to emphasize the importance of designing cities to be walkable (European Architectural History Network, 2022).

To analyze the walkability of a city, several factors come into play. One important factor on a small scale is pedestrian infrastructure. In order for a space to be walkable, sidewalks have to be easily accessible, direct, connected, safe, and comfortable (Frackelton et al., 2013; Aghaabbasi et

al., 2018). Furthermore, sidewalks that are designed for pedestrians to reach areas that have access to public transportation tend to make an urban area more walkable (Jeffrey et al., 2019). On a larger scale, adequate access to amenities such as schools, shops, restaurants, offices, parks, and gyms based on a region's population density encourages people to walk between their daily activities (Frank & Engelke, 2001; Saelens et al., 2003).

In the article "Utilitarian and Hedonic Walking: Examining the Impact of the Built Environment on Walking Behavior," the researchers found that the built environment had a major impact on whether or not people choose to walk from place to place. The authors mention that only 15% of walking trips have the destination as their sole focus (meaning that the walker doesn't care about the route), and 3% of trips had absolutely no destination in mind. The vast majority of urban walking trips therefore included a focus on both the destination and the route. This speaks to the importance of hedonic enjoyment, especially for planners and designers who want to encourage walking. The authors indicated that perceived attractiveness of the surroundings had positive psychological effects on the walker, which led to more walking. However, they found that perceived attractiveness was highly subjective, and feelings of safety were even more essential. These feelings focused on a person's knowledge of local crime and how much traffic there was along the path (with higher traffic being equated to greater safety).

The tools available to designers can greatly impact the ways in which we think about and approach problems. Thus, it is important that such tools point the way towards human-centered objectives. There are several existing walkability tools available for use by designers, but they tend to focus strongly on the utilitarian aspects of pedestrian routes. For example, the walk score definition provided in "Generative Urban Modeling: a Design Work Flow For Walkability-Optimized Cities" emphasizes the amount of errands one can complete without the use of a car (Rahka, 2023). These tools provide important insights about functionally improving the walkability of a neighborhood. This is achieved by changing land use planning, such as rearranging road and pedestrian networks, and then reevaluating how close a certain location is to certain amenities. However, such tools and methods can lead to a disconnect between the designers and the people living in these communities. It has been found that many of the utilitarian aspects of walkability do not increase the sense of community nor sociability for the end users (du Toit, 2007). Furthermore, most available tools entirely overlook hedonic factors affecting one's walk, such as the user's sense of safety, visual interest, and the amount of greenery along a route, which are very important factors in promoting walking as noted in the literature above. We seek to develop a tool that can provide designers with a new type of walk score centered around these human factors.

1.

3. Prior Work on Walkability Tools

3.1 Relevant Works

One readily available tool for analyzing walkability is a website called WalkScore (Hall and Ram, 2018). This website allows a user to input an address, and it returns a walkability score between 0 and 100. While we did find the walkability metric on WalkScore helpful, there are aspects of the method that we found lacking. For example, the "pedestrian friendliness" category only analyzes population density, block length, and intersection density. To improve this tool our team thought it would be helpful to include metrics to help an urban planner make pedestrian paths more enjoyable, such as providing feedback about how visually interesting a walk is or how much green space exposure there is. Furthermore, WalkScore doesn't produce visual feedback for its user; it only provides a number between 1 and 100.

The framework for WalkScore first involves inputting a physical address into the program, which then analyzes walking routes to nearby amenities (Hall & Ram, 2018). Points are awarded based on the distance to amenities in different categories. Amenities, such as grocery stores, or restaurants within a 5 minute walk (0.25 miles) are given maximum points, and a decay function is used to give reduced points to more distant amenities, with no points given after a 30 minute walk. The program also measures "pedestrian friendliness" by analyzing population density and road metrics such as block length and intersection density from data sources including Google, Factual, Great Schools, Open Street Map, the U.S. Census, Localeze, and information added by the WalkScore user community.

The Grasshopper plug-in called Elk is a walkability tool that allows a user to generate, manipulate, and export geographic data to perform spatial analysis for various urban design related projects. While Elk can visualize different features from geospatial data files, it does not provide its own interpretation or rating for walkability. Another downside of Elk is that it cannot work with GIS data as fluid as Urbano (discussed below). Lastly, the plug-in has not been updated since February of 2016, which seems to suggest designers analyzing geospatial data have not moved onto using other plug-ins.

Elk's framework uses various sources of geospatial data including OpenStreetMap data, GeoJSON files, shapefiles, and Shuttle Radar Topography Mission (SRTM) from USGS for analysis within Grasshopper. Some examples of the types of operations that can be performed with Elk include: visualizing data on maps and terrain models, performing spatial queries, such as finding points within a certain distance of a given location, and generating contour lines and terrain profiles. Once users import geospatial data into Grasshopper, Elk can be used to perform spatial analysis based on a list of map features that users can select from. The map features from this list include qualities such as "Historic," "Highway," "Tourism," and "Natural," among others, which could potentially serve as a starting point for generating our own metrics to categorize routes.

Urbano appears to be the most sophisticated walkability tool currently used by designers. Similar to Elk, it is a Grasshopper plug-in that allows users to create and manipulate urban elements, such as roads, buildings, and public spaces, using geospatial data (Dogan et al., 2020). We found that in general, Urbano contained all the Elk features we were interested in using along with more features. For example, the way buildings are visualized in Elk is that geometric data for a building footprint is taken and then that geometry just gets extruded to a building height. In Urbano, more realistic building facades are produced based on orthogonal approximation. But, for a few specific data reading features, Elk did produce more interesting results. Similar to Elk, Urbano does not interpret the walkability of a path; it only provides a means for data extraction and manipulation.

Urbano allows users to conduct various urban planning-related analyses, such as creating and editing street networks, generating building footprints and massing models, analyzing solar access and shading, performing pedestrian accessibility analyses, and evaluating urban density and building heights (Dogan et al., 2020). Urbano also features tools for analyzing GIS data, so that users can import and export GIS data for spatial analysis. The fact that Urbano is compatible with GIS is relevant to our project as we plan to use GIS to analyze the hedonic features of a site.

In summary, existing software is helpful to us but not sufficient to determine hedonic enjoyment of walks. WalkScore provides an example of a walkability software that focuses on utilitarian factors, with a framework for analysis based on walk times, similar to our distance-measuring method. Elk and Urbano help us turn geospatial data into maps that we can analyze for hedonic factors.

3.2 Significance of our Tool

Many existing walk score tools only analyze the utilitarian aspects of one's walk. Using the walk score definition provided in 'Generative Urban Modeling: a Design Work Flow For Walkability-Optimized Cities' each category is partitioned by the amount of errands one can complete without the use of a car (Rahka 2023). Walkability is determined by ranking the distance to various amenities and penalizing a low density of intersections. The large emphasis of utilitarian aspects of walkability is also present in many of the current tools that are available to urban planners who seek to improve walkability within their communities. These tools provide insight on how they can functionally improve the walkability of a neighborhood by changing land use planning and rearranging road and pedestrian networks and then reevaluating the proximity a certain location has to amenities. These tools and methodologies however neglect to factor in the hedonic factors that affect one's walk such as the user's sense of safety, interest as well as the level of greenery along the path of choice. These effects can be seen by the conclusions in "Does Walking in the Neighbourhood Enhance Local Sociability?" which found that a neighborhood's walkability when determined by utilitarian factors does not increase the citizens' sense of community nor sociability with others (du Toit, 2007). Given this disconnect between the two

important design characteristics, we seek to develop a tool that can bridge this gap and provide designers with a secondary walk score that is centered around human factors.

With the goal of incentivizing walking for leisure, it is important to define metrics that are strongly correlated with this parameter. “Perceived neighborhood environmental attributes associated with adults’ recreational walking: IPEN adult study in 12 countries” was a multi-country study that investigated environmental factors and determined the correlation between them and recreational walking amongst adults. In that study, there was a generally positive correlation between aesthetics, proximity to parks, land use mix, residential density, and overall neighborhood aesthetics. A similar study titled, “Perceived Environmental Aesthetics and Convenience and Company Are Associated with Walking for Exercise among Australian Adults,” also concluded that aesthetics were strongly correlated with recreational walking among urban Australian adults (Ball, 2001). Based on this literature, we decided to focus on providing designers with a metric for user interest which will factor in the path’s aesthetics. The tool will also highlight low interest areas along a path, allowing designers to see which areas may need redevelopment in order to maintain the interest of pedestrians.

In regard to perceived safety, many research articles have highlighted the negative correlation between crime and walkability. In Sugiyama’s multi-country study, it was found that participants who perceived a neighborhood as dangerous were less likely to walk for recreation (Sugiyama, 2014). This safety component includes a gendered dimension; for example, a research paper investigating walkability for women in San Francisco found that there is a negative correlation between the presence of homeless people and perceived walkability by women (Golan, 2019).

Finally, our tool will also focus on levels of greenery along the walking path. Green spaces have been shown to promote mental health, physical health, and longevity (van Herzele and de Vries, 2011). Wells and Laguarta (2010) found that people who live near green spaces were three times more likely to be physically active than people who did not; they also had a 40% lower risk of being overweight or obese. Walking in natural environments has also been shown to improve mental health more than walking in urban environments with low levels of nature (Cohen-Cline, Turkheimer, and Duncan, 2015), suggesting that green spaces are overall more pleasant to walk in than non-green spaces. Cohen-Cline and colleagues found that people who desire more physical activity tended to move into greener neighborhoods, since they know it will encourage them to get outside more. Another study (Takano, Nakamura, and Watanabe, 2002) reinforced these findings, additionally finding that physical activity in green spaces significantly increased longevity – even after adjusting for multiple confounding factors. Greenery has been shown to reduce perception of annoying environmental noise (Kozamernik, Rakuša, and Nikšič, 2020). Overall, nature has a major impact on enjoyment of an outdoor walk, and encourages people to engage in outdoor physical activity that they might not otherwise choose to do; for this reason we decided to use greenery as one of our three major influencing factors for our tool.

4. Implementation of our Tool

Our project aims to address the lack of tools available for urban planners to analyze hedonic factors of walking paths. At a high level, our Grasshopper script can be understood as a three-step process:

2. We import data from an OSM (OpenStreetMap) file to generate all the possible pedestrian paths for a given city or neighborhood.
3. We analyze the pedestrian path data and its relationship to hedonic factors for one given path.
4. We process the data and present it back to an urban planner in such a way that they can make informed design decisions regarding the improvement of the path's walkability.

This process is illustrated below in the following flow chart (***Figure 1***):

5.

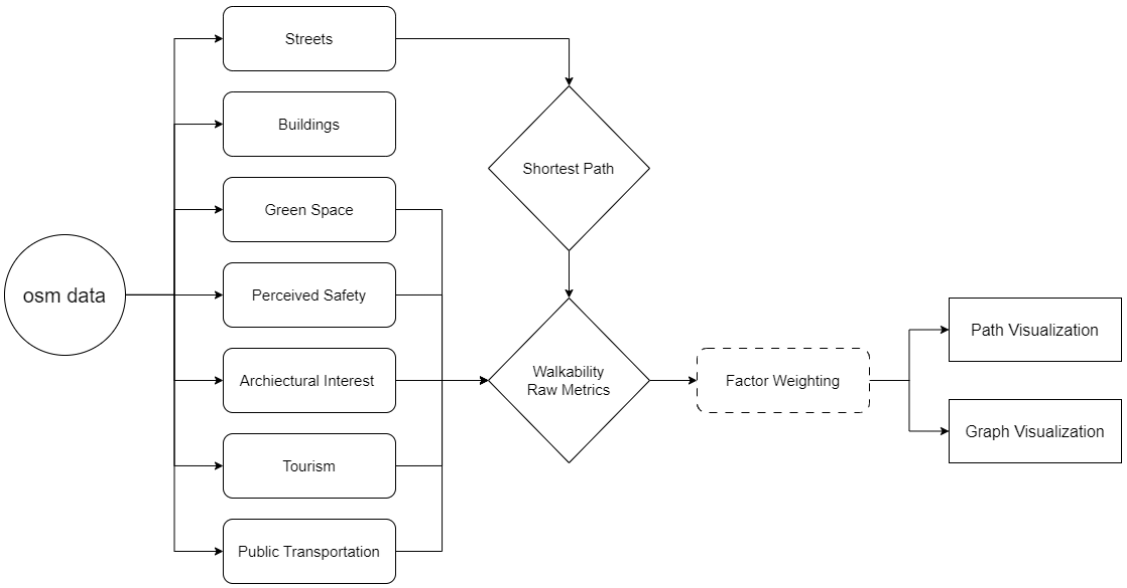


Figure 1*: Centipede Workflow Flowchart*

4.1 The Workflow

In step 1 of our process, we use OSM files to collect our map data because OpenStreetMap is the largest free and open geographic database. Furthermore, it is regularly updated and maintained, and Urbano and Elk can easily read OSM files. To make the OSM data readable in Grasshopper, though, Urbano and Elk convert the desired data to a tree of points structure, which can then be displayed in Rhino as the points themselves, or can be converted into polylines, surfaces, or BReps depending on what the data is.

Some of the walkability factors we were able to extract from Urbano and Elk were locations of greenspace, amenities (police and tourist destinations), public transportation stops, and historic monuments. With this data, we analyzed the walkability of specific paths a user could input. The following pictures (***figure 2***) highlight how simple it is for a user to use Urbano (left) and Elk

(right) to read an OSM file, and we show off the specific features available in each:

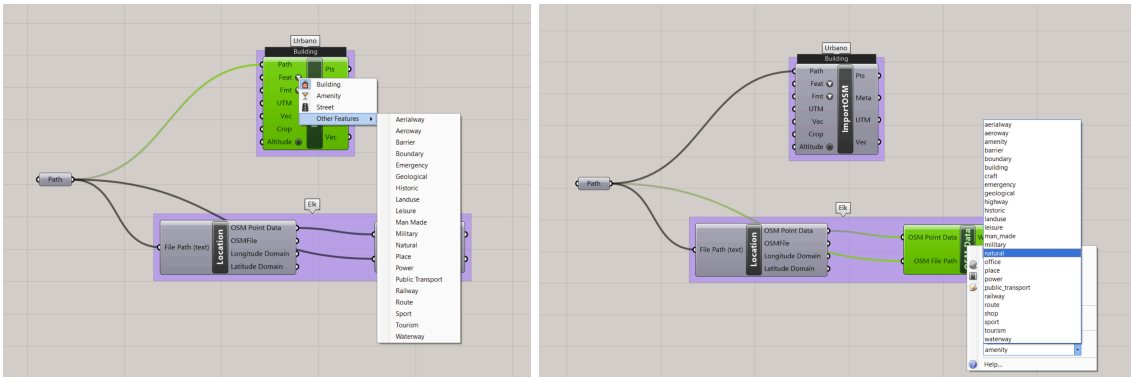


***Figure 2**: Reading OSM Files with Elk and Urbano*

4.2 Grasshopper Implementation

The next two images (***figure 3A/B***) show the script we wrote displays walking paths and buildings, as well as the final map visualization in Rhino. The OSM file being read in this example is of Cornell's campus.

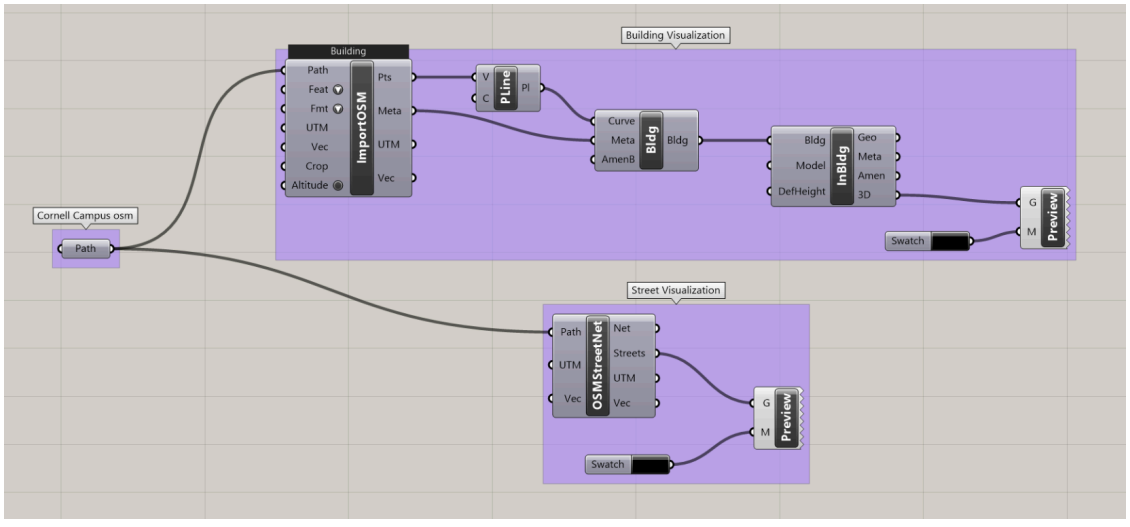


***Figure 3A**: Grasshopper Script to Read an OSM File*

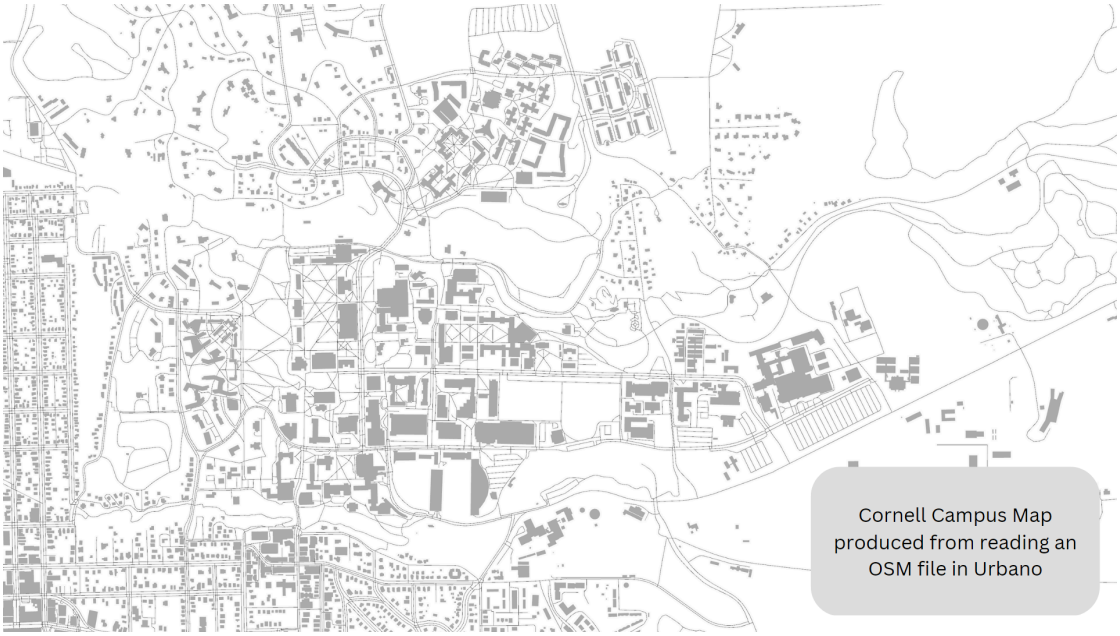


***Figure 3B**: Reading Building and Path Data from an OSM File*

The next step in our tool is to produce a path. We used a component from the Grasshopper toolbox called "Shortest Walk," which we downloaded from Food4Rhino. This component uses the A* shortest path algorithm to generate a path between two points. If a user wants to analyze a more specific walking route, they can add intermediate points along the path, too. Once the path is generated, our script subdivides it into segments that are 3 meters long and these points are later measured with their respective distances to walkability factors a designer includes. The shortest path script and final visualization is illustrated below in ***figure 4***. In this example, we display the shortest path from Clara Dickson Hall to Collegetown Bagels:

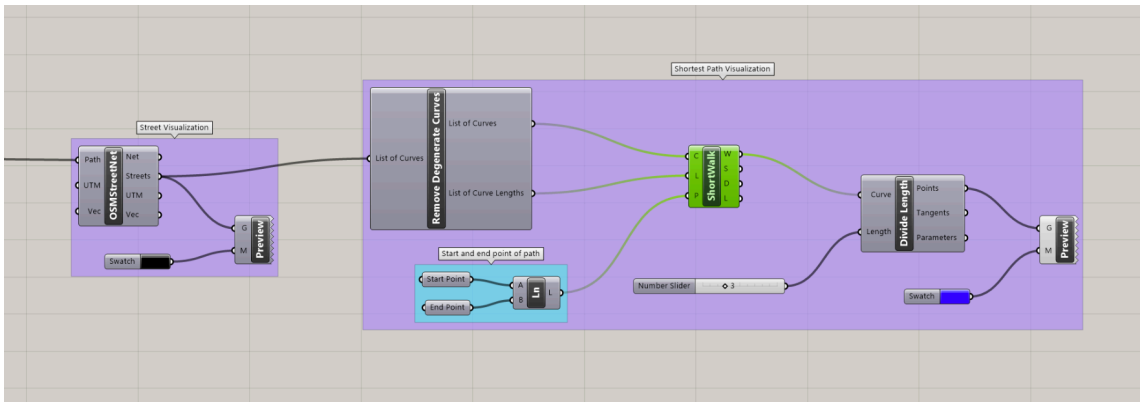


***Figure 4A**: Grasshopper Shortest Path Implementation*

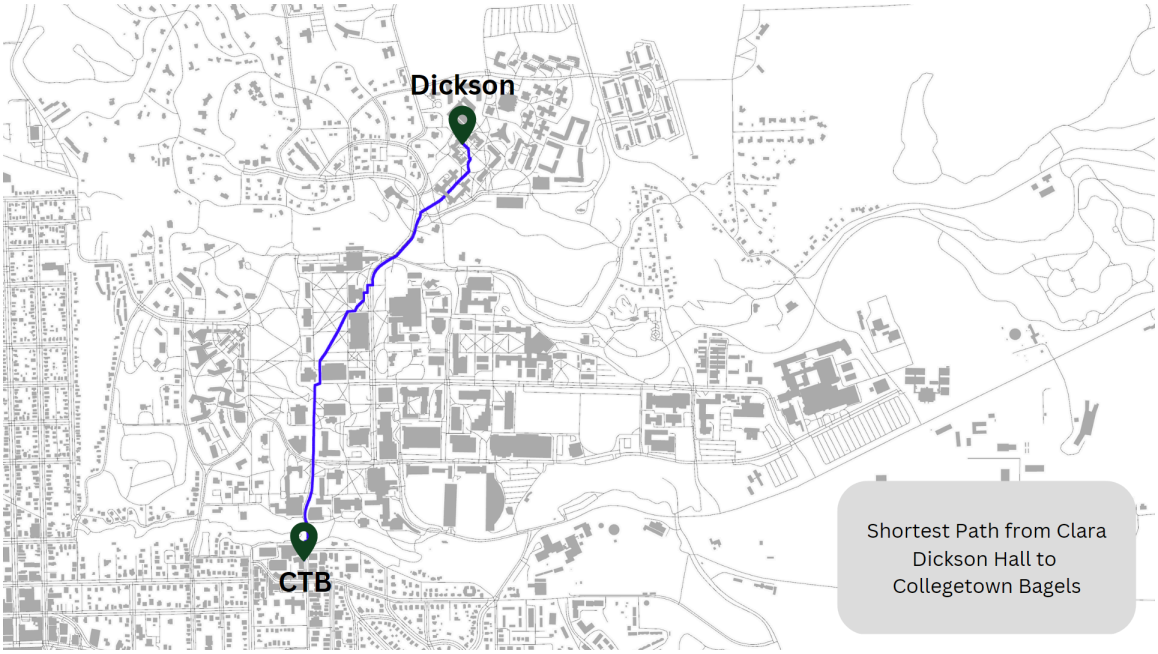


***Figure 4B**: Producing a Shortest Path Visualization*

The next step in our tool is to visualize the various hedonic factors. In our implementation, we simply got the locations of the various data as lists of points, and then created circles with the points at the center. ***Figure 5*** illustrates how we read the data and produced these circles using Urbano and Elk. In this example, we are reading all the greenspace identified around campus. The figure also shows what the final visualization ended up looking like when we overlaid it with our campus map.

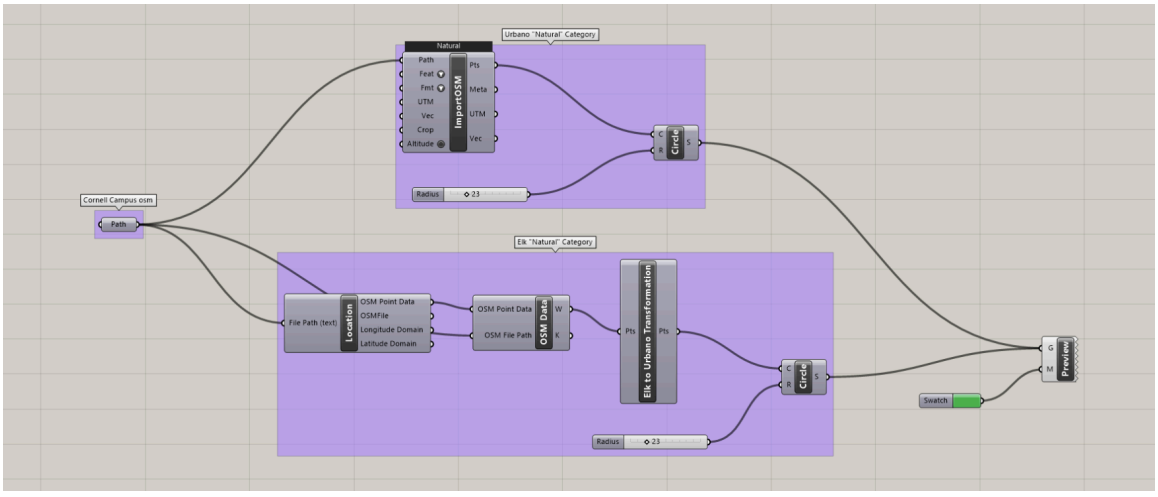


***Figure 5A:** Grasshopper Script for Green Space*

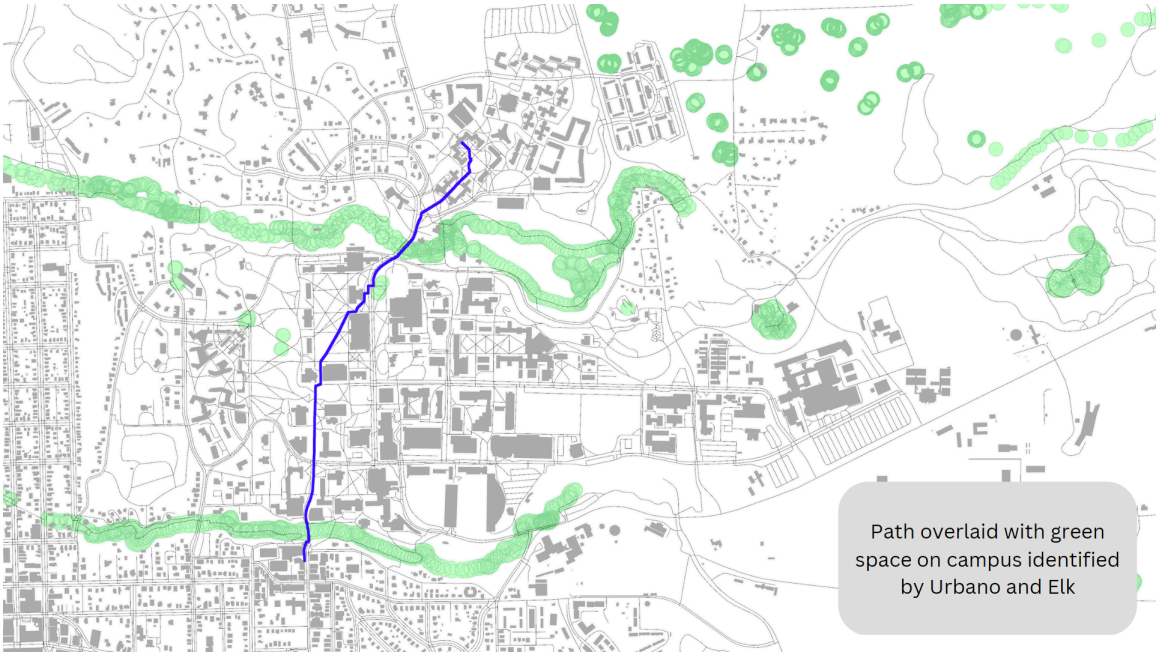


***Figure 5B**: Factor Location Visualization*

Using the location of the points along the path and the location of the hedonic factors, we then constructed an algorithm that calculates the distance between a given point on the path and each hedonic factor. The algorithm then omits all points but the ones nearest to the point along the path. The distances are visualized along a red to yellow to green gradient, where red is furthest away from a specified hedonic factor, and green is closest to the hedonic factor. In ***figures 6A/B***, we show how this process is applied to the path from a dorm to a restaurant and the greenspace hedonic factor.

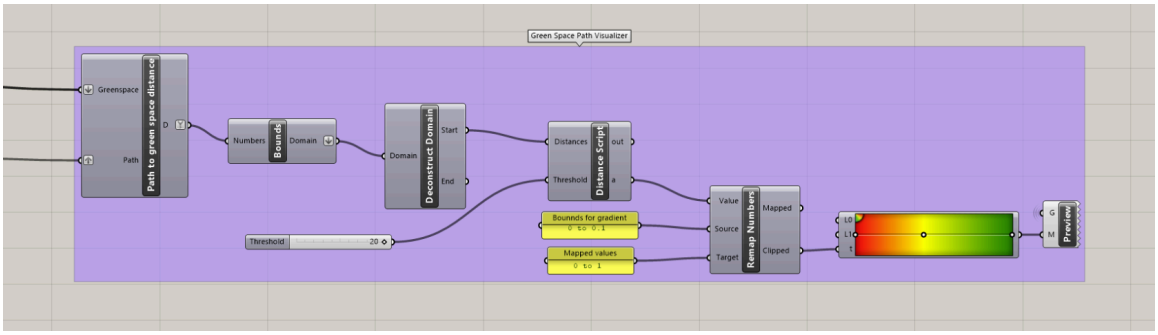


***Figure 6A:** Grasshopper Script for Green Space Path Visualizer*

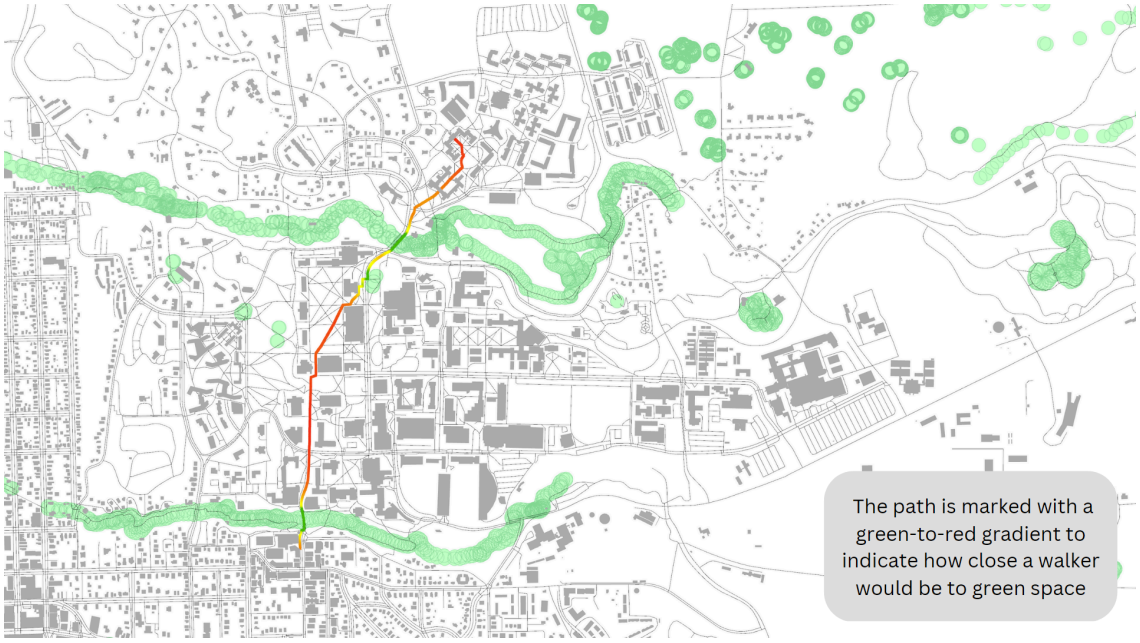


Figure 6B: *Visualization of how Close a Path is to Greenspace*

The other feature our tool offers is the ability for a user to visualize how human factors vary along a path with a stacked area chart. ***Figure 7A/B*** show our implementation of the greenspace chart in Grasshopper along with what it looks like for the greenspace along our path from a dorm to a restaurant.

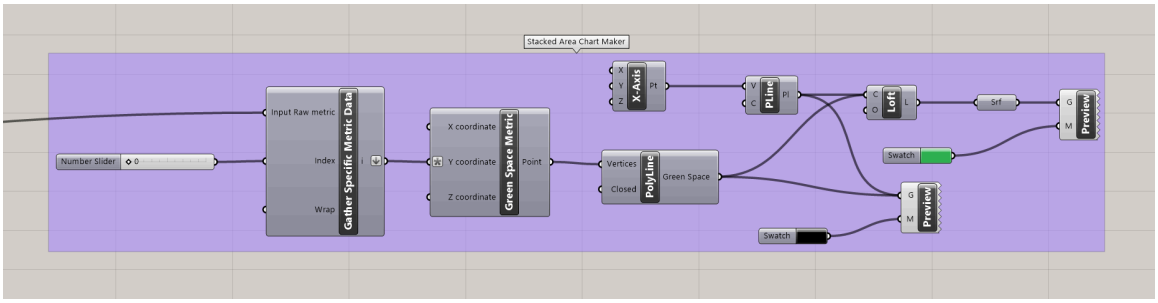


Figure 7A: Grasshopper Implementation of Stacked Area Chart

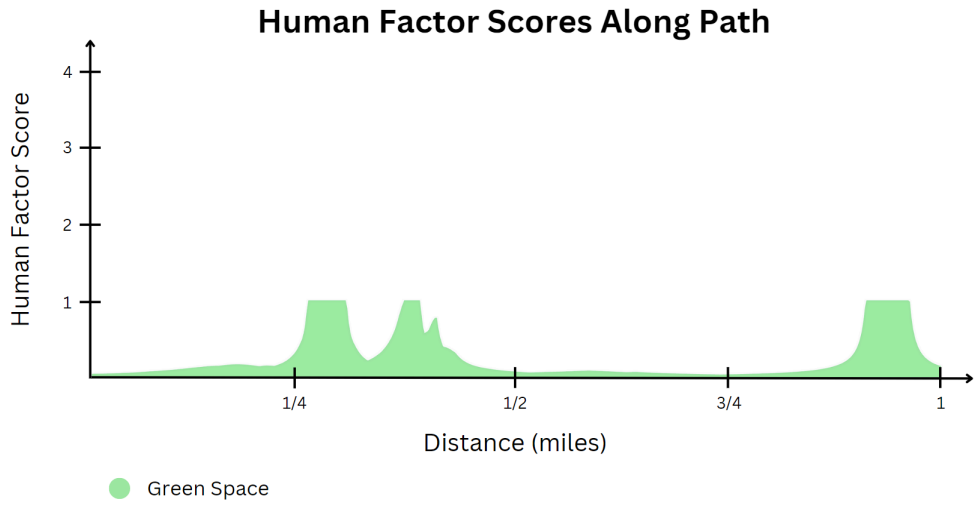


Figure 7B: *Greenspace Stacked Area Chart*

The process of picking a path, displaying hedonic factors, generating a path with a gradient, and showing the human factor score as a stacked area chart can be be repeated for other hedonic factors as well. ***Figure 8*** shows this process for all the factors we found from Elk and Urbano that were relevant to our literature review on the path from a dorm to a restaurant.

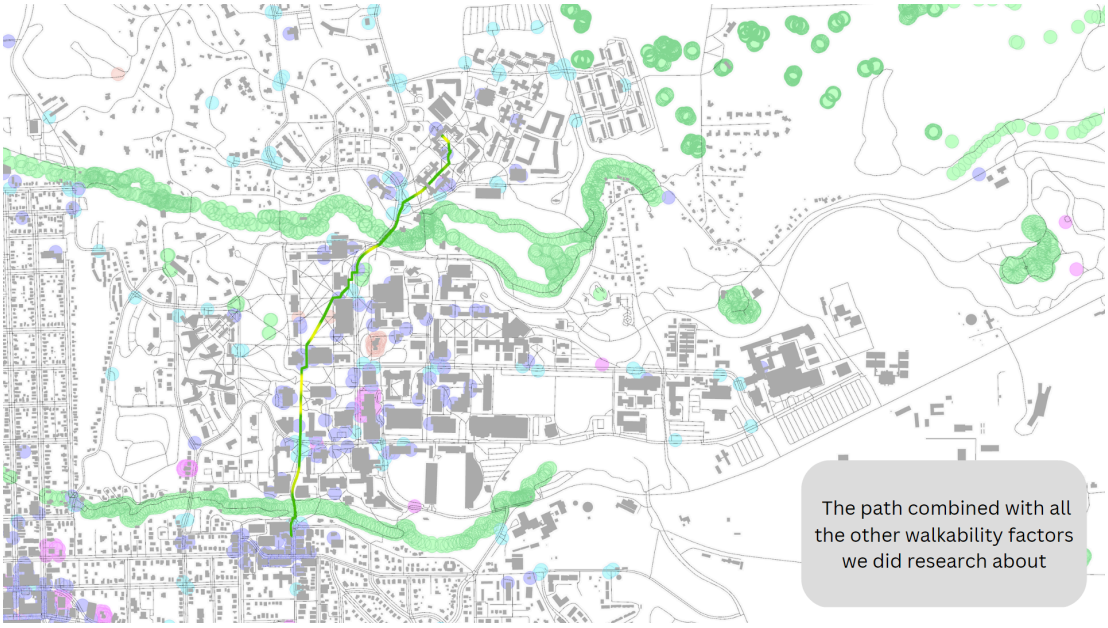


Figure 8A: *All Walkability Factors Displayed over Path*

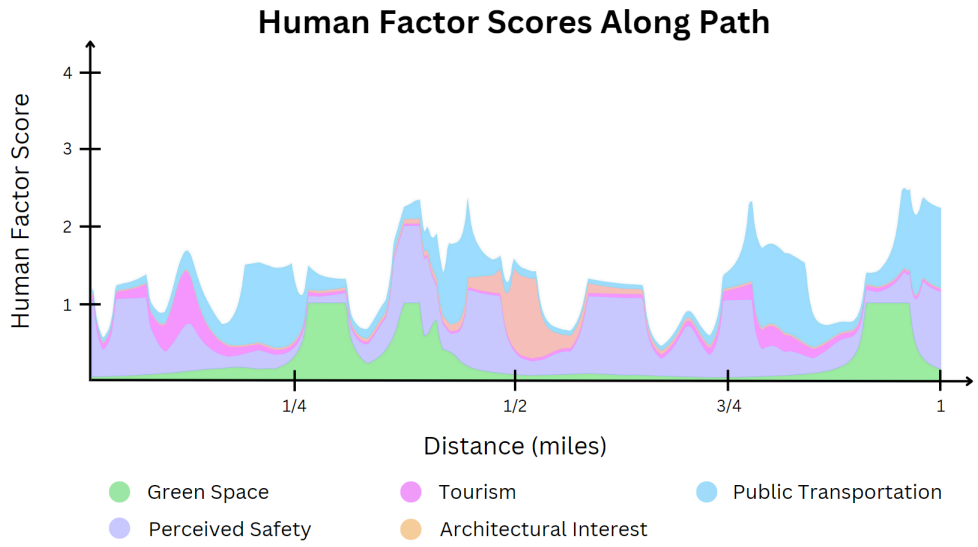


Figure 8B: *Human Factor Score Stacked Area Chart*

Another feature we included in our tool is the ability to weigh the hedonic factors according to the user's preferences. This allows users to prioritize certain factors over others based on their needs. As a proof of concept, our team conducted a small survey with 18 undergraduate students. In this survey we asked them the following questions:

1. How important is it for you to be immersed in green space when you take walks?
2. How important is it for you to feel safe on your walk (For example, if you are walking around Cornell, do you feel safer when you are closer to the blue light posts)?
3. How important is it for you to be near a bus stop or train station on your walk? Do you like having the option to take a bus if you get tired?
4. How important is it for you to walk past architecturally interesting buildings?
5. How important is it for you to walk past touristic sites?

Based on the responses, we generated relative weightings for our stacked area chart. The weightings we computed as a result of the survey are listed below:

1. Green Space: 1.45
2. Perceived Safety: 1.19
3. Access to Public Transportation: 0.87
4. Architectural Interest: 0.86
5. Touristic Sites: 0.63

Figure 9 shows the weighted stacked area chart that our tool generated in Grasshopper.

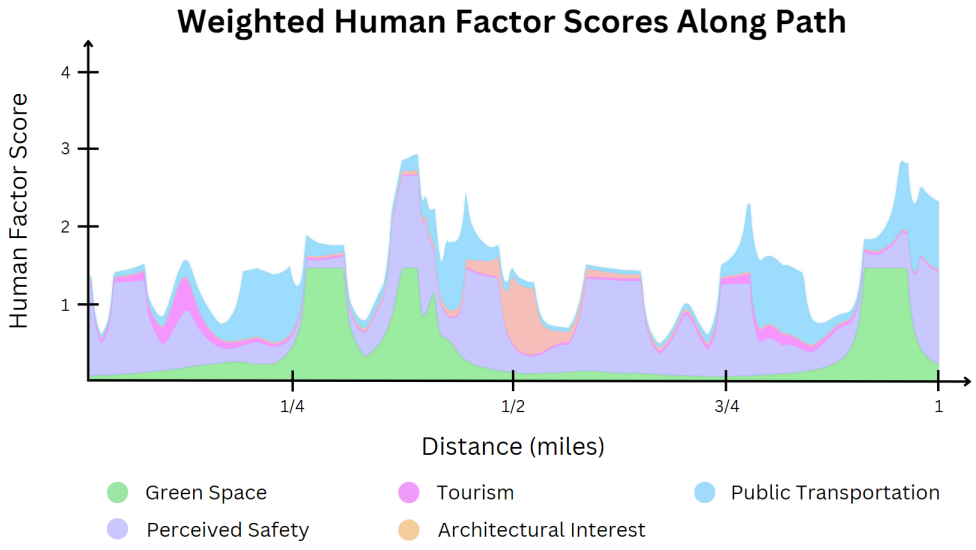


Figure 9: Weighted Stacked Area Chart

5. User Interface for Walkers

In order to make Centipede more user-friendly for walkers, we decided to prototype an app similar to Google or Apple Maps. Since the Grasshopper UI is clunky and unintuitive, we opted to make a mobile app to make Centipede more accessible. We used Figma to set up a prototype that displays the shortest path and its calculated walkability for user-set beginning and end points.

The app has a preset start point of Dickson Hall and an end point of Collegetown Bagels on College Ave. Once the user presses the Start button, the app displays the shortest path along with all factors highlighted on the map (***figure 10a***). By pressing the names of the factors in the lower half of the screen, the user can enable or disable them. Figure 10b shows the map with only Greenery enabled.

The button at the lower right of the screen, "View Graph", switches the lower half of the screen from toggling factors on and off to the stacked graph of factors along the walk. ***Figure 10c*** shows the graph with all factors enabled. ***Figure 10d*** shows the graph when only Greenery is enabled on the map.



***Figure 10 a-d**: Screen captures of Figma user app prototype.*

Our app prototype also offers an option to add extra time to your walk. After inputting the start and end points, the user selects "Add Extra Time", and the popup shown in Figure 11a appears, allowing them to add however much time they want and choosing which factors the program should optimize for when calculating the new path. Figure 11b shows the original walk from a dorm to a restaurant with 15 extra minutes of greenery, implemented by a detour around Beebe Lake. This feature, which we have not yet implemented into our Grasshopper program, helps the walker personalize their experience using Centipede and create a walk that's most enjoyable for them.

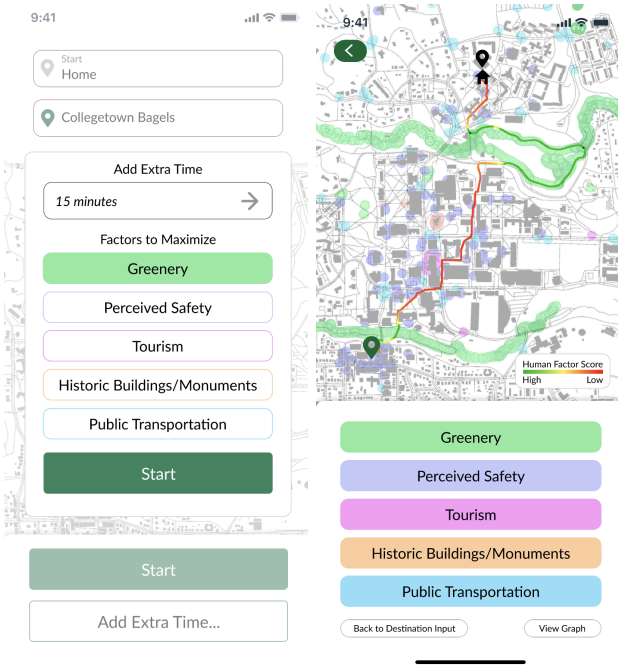


***Figure 11 a-b**: Adding extra time to a walk in the app prototype.*

6. Discussion

6.1 Summary of our findings

Our research and Grasshopper prototype has contributed to the development of a computational model that emphasizes the importance of human-centered factors in walkability. This is important as human-centered factors have not been prioritized in existing tools. The fact that Centipede prioritizes the needs of both urban planners/designers and walkers themselves also plays a significant role in the tool's contribution. Centipede will allow planners to better understand existing walkability patterns while improving the enjoyment of walks for pedestrian users. Planners will be able to use the stacked graph chart to analyze areas where there are lower levels of the hedonic factors. On the other hand, users will be able to select the hedonic factors on Centipede that they are interested in. This will prompt them to walk to their desired destination by making the walk more enjoyable.

We hope our project will help encourage other people to develop more tools for urban designers. We hope that our tool or tools like Centipede can become a standard tool used by urban planners and government bodies. For instance, planners can use the tool to convince government officials to invest in infrastructure improvements relating to walkability. Overall, Centipede will help governmental decision making processes become more evidence-based and holistic while encouraging walkability among residents.

6.2 Limitations

Given how Centipede is currently built upon OSM files for importing raw data, it can only be as accurate a representation of a location as is depicted in OSM. This can also be exacerbated over time if as cities evolve the OSM isn't updated. For example, in our prototype none of Cornell's main quads are labeled as green space on the map which isn't representative of the actual geography. As a result for cities that are not well mapped our tool will have limited utility. Designers could overcome this by surveying plots of land that they are going to work on and then upload it into OSM to use on their project.

Secondly, Centipede is not customizable for individual users. Currently, our model is based on data from a study conducted in 12 countries. From this a general model was formed to fit this sample. However, in cases where this sample is not representative of a population and on an individual scale, the needs of users are subject to change. Thus, the current model may not hold for certain cities or demographics such as women and people of color. Furthermore, users are not able to input their age, gender, or accessibility nor change factor weightings to their liking to overcome this issue. Lastly, Centipede does not account for topography which is a major factor affecting the utilitarian aspects of one's walk. Users may not be able to traverse steep slopes or climb flights of stairs thus generating a disconnect between the app and the end user.

6.3 Future Research

Our current implementation only allows users to select factors

To Overcome some of Centipede's current limitations our next steps include incorporating Grasshopper's TOPOkit toolbox, and allowing users the ability to change their factor weightings and select features that they would like to avoid. The TOPOkit toolbox is a Grasshopper plugin that can be used to create topographies in Rhino using data acquired from lidar scans. Centipede can then use the terrain map to find paths that do not traverse step slopes. In addition to this, the ability for users to be able to customize parameters such as factor weightings and provide constraints such as features along a path to avoid entirely thus directly addressing the issues surrounding user customization.

Maybe use another wayfinding algorithm to maximize the human factors; do a survey about whether the figures we made would be useful; Does the potential user interface look appealing?

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