CrowDPLoS: a Feasibility Study to Assess the Level of Service for Disabled People on Pedestrian Urban Network Using Computer Vision and Crowdsourcing

Anonymous VCIP Submission
Paper ID:

Abstract—**Availability of global and scalable tools to assess disabled pedestrian level of service (DPLoS) is not yet reached. This study aims to fulfill the needs of the mobility-impaired street users using Computer Vision (CV) techniques and Crowdsourcing (CS) to reach a high precision rate on several indicators like curb ramps, quality and slope of sidewalks, secured crosswalks or street coating.**

These indicators are evaluated and aggregated in a DPLoS global value for each edges of a pedestrian network. The establishment of the pedestrian graph rely both on Open-StreetMaps (OSM) data, CV and crowd.workers.

Finally, a mobile routing application will make possible to propose the best route to the end user. He will as well be given the opportunity to update the data with valuable and up-to-date field observations.

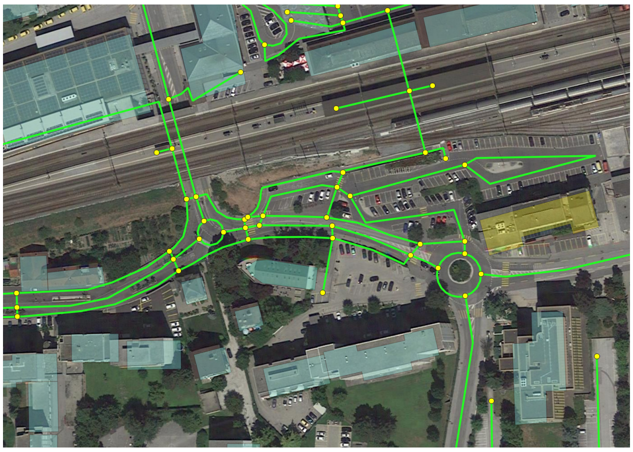

Figure 1. Part of the pedestrian network extracted from OpenStreetMap (OSM) data (green) in a downtown area. On can clearly see that sidewalks information is not present everywhere. Background map: google satellite imagery.

I. Introduction

A. The CrowDPLoS project

In Europe, 65+ aged proportion could raise from less than 20% in 2010 up to more than 30% by 2050 [1] and this trend may be even greater in other regions of the world.

CrowDPLoS is thought as an interdisciplinary research project at the boundary of Computer Vision (CV) and Crowdsourcing (CS). It aims to give impaired people, mainly wheelchair users, a mean to travel safely and with ease through a modern urban area. The key and target idea is to propose a mobile routing application based on a pedestrian network which edges attributes are features scores characterizing urban pathways for impaired. Each individual feature score is then weighted through a model which gives the edges a disabled pedestrian level of service (DPLoS) global score. The key point is to extract features from different sources of geolocated street images. The extraction will rely both on crowd-workers and CV detection algorithms.

The project is divided into four main development axes:

- **DPLoS model**; definition and choice of each individual feature and making of the DPLoS model,
- **CS**; assessing advantages and drawbacks of different crowdsourcing approaches, especially VGI regarding impaired mobility in an urban area; how may it help to acquire, check and validate data both for the pedestrian graph and each of the features encountered in the field,
- **CV**; detecting the presence of the defined indicators on street based or aerial geolocated images,
- **Routing**; establishing a pedestrian graph (fig.1) that is suitable for routing based on the DPLoS value for each edge.

CV techniques shall be used combined with Machine Learning (ML) to parse huge images datasets faster. Some higher quality local field data must also be included with a citizen-driven CS approach. Coupling of both will make it possible to provide:

- almost continuously near up-to-date critical data
- labeled data to vision algorithms
- a way to check and validate some results of the detection algorithms
- a better integration of mobility impaired needs by local planners

II. Related work

A. Crowdsourcing

Crowdsourcing is the recent research field which focus on how to include people, mainly final-users, in the development and the design of a product [2]. This may be game-oriented to maximize the number of crowd-workers and their motivation as well as to keep them participating as long as possible [3], [4].

When data are collected by citizen, one talk about Citizen Science. If these data have a strong geospatial component, this lead to the field of Volunteered Geographic Information (VGI) [5]. Brovelli et al. [6] and Minghini [7] shown how Participatory GIS using Free and Open Source Software (FOSS) may help providing high quality open-GIS data and making them available to the general public using web technologies. Brovelli et al. [8] also shown how VGI may improve urban monitoring and planing or tourism with mobile-based applications.

In labeling tasks, some great care must be taken to maintain data quality. Gamification principles may be an invaluable help to keep users motivation and quality of their work [9], [10].

The OpenSideWalks project also takes benefits from Crowdsourcing [11], [12] to collect high quality open data.

B. *Computer Vision based techniques*

Historically, CV tends to extract features from images like edges [13]. Segmentation by watershed algorithms [14], [15] using graph-based techniques [16] or oriented gradient [17] gives the ability to well enough isolate regions on an image. Hough transform is also a well know line detector that may be used to extract road boarders [18], [19], [20], [21] as well as vanishing point extraction [22], [23], [24].

Sky views are also known to provide good enough classification results, especially for crosswalks detection [25].

[26] shows a simple approach to calculate the slope of a street by using lines which are known to be horizontal, like building windows edges.

It has already been shown [27], [28] how CV was used to determine accessibility from physical features of the real world based on GSV. This approach is making use of ML techniques, especially Convolutional Neural Networks (CNN) which are typically designed to extract features from images [29]. Field of autonomous driving brings a solid background for street segmentation using ML [30], even coupled with stereoscopic images which provides the useful depth information [31], [32]. [33] used a more global approach coupled with a random forest classifier to identify sidewalks on street view images.

C. *Coupling CS and CV algorithms to the DPLoS model*

Level of Service (LoS) has long been studied for pedestrian (PLoS) [34], [35]. The former proposed a model that can help crossroads design and prioritize the needs for local governments.

As sidewalks are probably the most important and secure places for pedestrian to walk on in urban areas, several studies have focused their researches on characterizing and assessing sidewalks accessibility.

[36] compared the gap between the subjective security perception of pedestrian with traffic flow characteristics.

But it's rather new that a PLoS has been specifically investigated for disabled people (DPLoS). [37] have for example calculated 10 main feature indicators. These indicators are themselves based on several studies and guidelines regarding facilities for disabled like wheelchair users or blind people. [38], [39] focused on mapping the level of accessibility of street networks and [40], [41] on creating an accessibility mapping mobile application (MEP: Map for Easy Paths) using a user-centered design approach.

[31] and [42] used calculated depth map to detect negative obstacle edges on wheelchair users path by directly embedding a stereo camera onto the wheelchair.

Other embedded based techniques make use of a smartphone camera to detect crosswalk [43] or straight paths using CV and stereo vision [44].

OpenSideWalk [45] investigated sidewalk graph analysis for routing to propose the better paths for disabled people. This project is now proposing a schema to better and more finely represents sidewalks as separate footways from the drivable roads in OpenStreetMap (OSM).

Even the tourism industry may take some advantages of disabled accessibility researches [46].

While [47] addressed some of the most important questions regarding CV and CS and provide useful general guideline, it is only recently that DPLoS assessment or application design took advantages of CS and CV. [48], [41] have shown the opportunity of integrating final users in the design of an application devoted to disabled pedestrian and to assess scaled street segments aptitude.

Some of the most advanced studies [49], [50] have shown how to combine CS and CV on Google Street View (GSV) images to collect informations on disabled pedestrians accessibility. The built tools [27] make use of Amazon Mechanical Turk (AMT) to achieve rapidly and at low cost some detection tasks on images. Recall of AMT workers combined with CV algorithms is higher and faster than AMT workers alone [51], [52], [53]. Thus, CV still endorse an important role in detecting features, especially when combined with ML.

The bottleneck in such approach is data acquisition and labeling. The latter is one of the highest time demanding operation. Thus, finding a pleasant way to annotate images with the highest quality is a key factor in this task [10].

III. PROPOSED APPROACH

Based on the relevant literature, the research proposal is articulated in several phases. Two first preliminary steps will be:

- the creation of the DPLoS model and
- the establishment of a pedestrian network at a city-scale level

Meanwhile, CV+ML algorithms dedicated to features detections in images will be settled together with dedicated CS applications to collect data, digitize and label features and evaluate the detection results.

These two steps must be closely related in their development as part of user inputs may influence CV+ML detection algorithms and algorithms results must be evaluated by crowd-workers and final users.

A. *DPLoS model*

The DPLoS established model retains the 5 following features and value ranges:

- slope
- sidewalks width and obstacles
- coating quality (pavement, smooth concreet)
- crosswalks and security signals (pedestrian light, refuge island)
- presence of curb ramps to cross roads

B. Pedestrian graph

Existing vector data to establish the pedestrian graph may include National Map Agency (NMA) Cadastral Survey or vector data if available, OSM streets and footways or third party road networks.

It is also conceivable to use high resolution satellite data to extract a road network using segmentation-based classification methods in regions where high quality vector data does not exist.

For this study, OSM street pathways data were extracted using a dedicated Python package [54].

C. Crowdsourcing, Computer Vision and Machine Learning

It was first decided not to use one, but rather 4 different stages depending on the goal to achieve. These goals are as follows:

1) Footways network making of and update
2) Data acquisition: raw images + geolocation
3) Images features digitizing and labeling
4) End-user route choice and update abilities

Footways network update: The initial pedestrian network may not be totally fulfilled 1. It will be proposed as a Tool-as-a-Game (TaaG) to give crowd-workers a way to complete or make it fit the actual reality more precisely based on a recent orthophoto background.

Data acquisition and geolocation + network segmentation: The second stage, would basically serve as a feeding source for raw images.

Everyone can take a picture with a mobile device and upload it to a database. Along with existing street pictures sources like GSV or mapillary [55], [56] they will serve as raw data input for the digitizing step. If a mobile GNSS receiver and a compass are enabled, geolocation values are stored along the picture. Otherwise, a geolocation tool will proposed to the user to geolocate and orient (azimuth) its photograph before uploading it.

Feature digitizing and characterizing: This third stage main goal is to digitize one or more of the 5 identified DPLoS features on raw images and marking them with attributes scores based on the DPLoS model.

E.g., if someone sees a curb ramp on a picture, he will be able to digitize it and marking it as a curb ramp 2. An other example would let the user annotate a sidewalk surface width as "no possible way for a single wheelchair" based on the perceived width on the given picture. If depth information is available a measuring tool may also be provided.

This second application will also give the user a TaaG to check the features that were detected by algorithms. This important step provides two advantages:

1) it will classify detected features according to a confusion matrix I.

Figure 2. An example on digitizing a curb ramp on a picture.

Table I
CONFUSION MATRIX

		Detection	
		Positive	Negative
Ground truth	Positive	True positive	False negative
	Negative	False positive	True negative

2) ML detection algorithms abilities could be improved by feeding them back these new positive and negative labeled images for a new training. Training results must be tracked to avoid overfitting.

End-user route choice and update: The last application will target the impaired pedestrian street users. It will propose the best route between two points based on the better DPLoS edges as define by eq. 1.

$$\text{DPLoS}_{route} = \frac{1}{n}\sum \text{DPLoS}_{n \cdot segment} \tag{1}$$

An additional tab will offer the user the possibility to give its feedback on a selected segment, for example when he sees an inadequate between the real world and a feature on the segment. This will improve the pedestrian network and update it as urban environment is changing.

IV. CONCLUSION AND FUTURE WORK

This project is in its early stages. The first version of the DPLoS model is ready. The setting up of a database to store images metadata like geolocation, as well as algorithms and crowd-workers labeling results is taking place. This same database will serve the four different applications through APIs that need to be developed. It will finally need further investigating and tests regarding coupling of CV and ML algorithms. Database populating and labeling will be the most resource demanding tasks.

REFERENCES

[1] A. Walker and T. Maltby, “Active ageing: A strategic policy solution to demographic ageing in the european union,” *International Journal of Social Welfare*, vol. 21, no. s1, 2012.

[2] A. Ghezzi, D. Gabelloni, A. Martini, and A. Natalicchio, “Crowdsourcing: A Review and Suggestions for Future Research,” *International Journal of Management Reviews*, pp. n/a–n/a, Jan. 2017.

[3] Z. Zeng, J. Tang, and T. Wang, “Motivation mechanism of gamification in crowdsourcing projects,” *International Journal of Crowd Science*, vol. 1, no. 1, pp. 71–82, Mar. 2017.

[4] B. Morschheuser, J. Hamari, J. Koivisto, and A. Maedche, “Gamified crowdsourcing: Conceptualization, literature review, and future agenda,” *International Journal of Human-Computer Studies*, vol. 106, no. Supplement C, pp. 26–43, Oct. 2017.

[5] M. Haklay, "Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation," in *Crowdsourcing Geographic Knowledge*, D. Sui, S. Elwood, and M. Goodchild, Eds. Dordrecht: Springer Netherlands, 2013, pp. 105–122, dOI: 10.1007/978-94-007-4587-2_7.

[6] M. A. Brovelli, M. Minghini, and G. Zamboni, "Web–based Participatory GIS with data collection on the field – A prototype architecture," *OSGeo Journal*, vol. 13, no. 1, pp. 29–33, Apr. 2014.

[7] M. Minghini, "Multi-dimensional GeoWeb platforms for citizen science and civic engagement applications," Tesi di dottorato, Mar. 2014.

[8] M. A. Brovelli, M. Minghini, and G. Zamboni, "Public participation in GIS via mobile applications," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 114, no. Supplement C, pp. 306–315, Apr. 2016.

[9] L. von Ahn and L. Dabbish, "Labeling Images with a Computer Game," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '04. New York, NY, USA: ACM, 2004, pp. 319–326.

[10] L. Von Ahn, R. Liu, and M. Blum, "Peekaboom: a game for locating objects in images," in *Proceedings of the SIGCHI conference on Human Factors in computing systems*. ACM, 2006, pp. 55–64.

[11] "OpenSidewalks."

[12] A. Tanweer, N. Bolten, M. Drouhard, J. Hamilton, A. Caspi, B. Fiore-Gartland, and K. Tan, "Mapping for accessibility: A case study of ethics in data science for social good," *arXiv:1710.06882 [cs]*, Oct. 2017, arXiv: 1710.06882.

[13] J. Canny, "A Computational Approach to Edge Detection," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAMI-8, no. 6, pp. 679–698, Nov. 1986.

[14] F. Meyer and S. Beucher, "Morphological segmentation," *Journal of Visual Communication and Image Representation*, vol. 1, no. 1, pp. 21–46, Sep. 1990.

[15] S. Beucher and F. Meyer, *Segmentation: The Watershed Transformation. Mathematical Morphology in Image Processing*, Jan. 1993, vol. 34.

[16] P. F. Felzenszwalb and D. P. Huttenlocher, "Efficient Graph-Based Image Segmentation," *International Journal of Computer Vision*, vol. 59, no. 2, pp. 167–181, Sep. 2004.

[17] T. Malisiewicz, A. Gupta, and A. A. Efros, "Ensemble of exemplar-SVMs for object detection and beyond," in *2011 International Conference on Computer Vision*, Nov. 2011, pp. 89–96.

[18] R. O. Duda and P. E. Hart, "Use of the Hough Transformation to Detect Lines and Curves in Pictures," *Commun. ACM*, vol. 15, no. 1, pp. 11–15, Jan. 1972.

[19] J. Illingworth and J. Kittler, "A survey of the hough transform," *Computer Vision, Graphics, and Image Processing*, vol. 44, no. 1, pp. 87–116, Oct. 1988.

[20] D. H. Ballard, "Generalizing the Hough transform to detect arbitrary shapes," *Pattern Recognition*, vol. 13, no. 2, pp. 111–122, Jan. 1981.

[21] N. Kiryati, Y. Eldar, and A. M. Bruckstein, "A probabilistic Hough transform," *Pattern Recognition*, vol. 24, no. 4, pp. 303–316, Jan. 1991.

[22] S. Se and M. Brady, "Road feature detection and estimation," *Machine Vision and Applications*, vol. 14, no. 3, pp. 157–165, Jul. 2003.

[23] Y. Wang, E. K. Teoh, and D. Shen, "Lane detection and tracking using b-snake," *Image and Vision computing*, vol. 22, no. 4, pp. 269–280, 2004.

[24] H. Kong, J.-Y. Audibert, and J. Ponce, "Vanishing point detection for road detection," in *Computer Vision and Pattern Recognition, 2009. CVPR 2009. IEEE Conference on*. IEEE, 2009, pp. 96–103.

[25] R. F. Berriel, A. T. Lopes, A. F. d. Souza, and T. Oliveira-Santos, "Deep Learning-Based Large-Scale Automatic Satellite Crosswalk Classification," *IEEE Geoscience and Remote Sensing Letters*, vol. 14, no. 9, pp. 1513–1517, Sep. 2017.

[26] Y. Lu and H. A. Karimi, "Real-Time Sidewalk Slope Calculation through Integration of GPS Trajectory and Image Data to Assist People with Disabilities in Navigation," *ISPRS International Journal of Geo-Information*, vol. 4, no. 2, pp. 741–753, 2015.

[27] K. Hara, J. Sun, R. Moore, D. Jacobs, and J. Froehlich, "Tohme: Detecting Curb Ramps in Google Street View Using Crowdsourcing, Computer Vision, and Machine Learning," in *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*, ser. UIST '14. New York, NY, USA: ACM, 2014, pp. 189–204.

[28] K. Hara, C. Chan, and J. E. Froehlich, "The Design of Assistive Location-based Technologies for People with Ambulatory Disabilities: A Formative Study," in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ser. CHI '16. New York, NY, USA: ACM, 2016, pp. 1757–1768.

[29] Y. LeCun, Y. Bengio *et al.*, "Convolutional networks for images, speech, and time series," *The handbook of brain theory and neural networks*, vol. 3361, no. 10, p. 1995, 1995.

[30] J. M. Alvarez, T. Gevers, Y. LeCun, and A. M. Lopez, "Road scene segmentation from a single image," in *European Conference on Computer Vision*. Springer, 2012, pp. 376–389.

[31] J. M. Coughlan and H. Shen, "Terrain Analysis for Blind Wheelchair Users: Computer Vision Algorithms for Finding Curbs and other Negative Obstacles." in *CVHI*, 2007.

[32] J. Zbontar and Y. LeCun, "Stereo matching by training a convolutional neural network to compare image patches," *Journal of Machine Learning Research*, vol. 17, no. 1-32, p. 2, 2016.

[33] V. Smith, J. Malik, and D. Culler, "Classification of sidewalks in street view images," in *2013 International Green Computing Conference Proceedings*, Jun. 2013, pp. 1–6.

[34] B. Landis, V. Vattikuti, R. Ottenberg, D. McLeod, and M. Guttenplan, "Modeling the Roadside Walking Environment: Pedestrian Level of Service," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1773, pp. 82–88, Jan. 2001.

[35] N. Gallin, "Quantifying pedestrian friendliness–guidelines for assessing pedestrian level of service," *Road & Transport Research*, vol. 10, no. 1, p. 47, 2001.

[36] D. Tan, W. Wang, J. Lu, and Y. Bian, "Research on Methods of Assessing Pedestrian Level of Service for Sidewalk," *Journal of Transportation Systems Engineering and Information Technology*, vol. 7, no. 5, pp. 74–79, Oct. 2007.

[37] Asadi-Shekari Zohreh, Moeinaddini Mehdi, and Zaly Shah Muhammad, "Disabled Pedestrian Level of Service Method for Evaluating and Promoting Inclusive Walking Facilities on Urban Streets," *Journal of Transportation Engineering*, vol. 139, no. 2, pp. 181–192, Feb. 2013.

[38] M. Mostafavi, "Mobilisig: Development of a geospatial assistive technology for navigation of people with motor disabilities," in *Spatial Knowledge and Information Conference. Banff, Alberta, Canada*, 2015.

[39] A. Gharebaghi, M.-A. Mostafavi, G. Edwards, P. Fougeyrollas, P. Morales-Coayla, F. Routhier, J. Leblond, and L. Noreau, "A confidence-based approach for the assessment of accessibility of pedestrian network for manual wheelchair users," in *International Cartographic Conference*. Springer, 2017, pp. 463–477.

[40] Z. Liu, N. Glassey Balet, S. Maria, and E. De Gaspari, "Crowdsourcing-Based Mobile Application for Wheelchair Accessibility," *Journal on Technology & Persons with Disabilities*, vol. 5, pp. 1–15, Apr. 2017.

[41] S. Comai, D. Kayange, R. Mangiarotti, M. Matteucci, S. Ugur Yavuz, and F. Valentini, "Mapping city accessibility: review and analysis," *Stud. Health Technol. Inform*, vol. 217, pp. 325–331, 2015.

[42] V. Ivanchenko, J. Coughlan, W. Gerrey, and H. Shen, "Computer vision-based clear path guidance for blind wheelchair users," in *Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility*. ACM, 2008, pp. 291–292.

[43] V. Ivanchenko, J. Coughlan, and H. Shen, "Crosswatch: A Camera Phone System for Orienting Visually Impaired Pedestrians at Traffic Intersections," in *Computers Helping People with Special Needs*, ser. Lecture Notes in Computer Science. Springer, Berlin, Heidelberg, Jul. 2008, pp. 1122–1128.

[44] M. Asad and W. Ikram, "Smartphone based guidance system for visually impaired person," in *2012 3rd International Conference on Image Processing Theory, Tools and Applications (IPTA)*, Oct. 2012, pp. 442–447.

[45] N. Bolten, A. Amini, Y. Hao, V. Ravichandran, A. Stephens, and A. Caspi, "Urban Sidewalks: Visualization and Routing for Individuals with Limited Mobility," in *Proceedings of the 1st International ACM SIGSPATIAL Workshop on Smart Cities and Urban Analytics*, ser. UrbanGIS'15. New York, NY, USA: ACM, 2015, pp. 122–125.

[46] A. A. Israeli, "A Preliminary Investigation of the Importance of Site Accessibility Factors for Disabled Tourists," *Journal of Travel Research*, vol. 41, no. 1, pp. 101–104, Aug. 2002.

[47] A. Kovashka, O. Russakovsky, L. Fei-Fei, K. Grauman *et al.*, "Crowdsourcing in computer vision," *Foundations and Trends® in Computer Graphics and Vision*, vol. 10, no. 3, pp. 177–243, 2016.

[48] K. Hara, V. Le, and J. Froehlich, "A Feasibility Study of Crowdsourcing and Google Street View to Determine Sidewalk

Accessibility," in *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS '12. New York, NY, USA: ACM, 2012, pp. 273–274.
[49] K. Hara, "Scalable Methods to Collect and Visualize Sidewalk Accessibility Data for People with Mobility Impairments," in *Proceedings of the Adjunct Publication of the 27th Annual ACM Symposium on User Interface Software and Technology*, ser. UIST'14 Adjunct. New York, NY, USA: ACM, 2014, pp. 1–4.
[50] K. Hara and J. E. Froehlich, "Characterizing and Visualizing Physical World Accessibility at Scale Using Crowdsourcing, Computer Vision, and Machine Learning," *SIGACCESS Access. Comput.*, no. 113, pp. 13–21, Nov. 2015.
[51] K. Hara, V. Le, and J. Froehlich, "Combining Crowdsourcing and Google Street View to Identify Street-level Accessibility Problems," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '13. New York, NY, USA: ACM, 2013, pp. 631–640.
[52] K. Hara, S. Azenkot, M. Campbell, C. L. Bennett, V. Le, S. Pannella, R. Moore, K. Minckler, R. H. Ng, and J. E. Froehlich, "Improving Public Transit Accessibility for Blind Riders by Crowdsourcing Bus Stop Landmark Locations with Google Street View," in *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS '13. New York, NY, USA: ACM, 2013, pp. 16:1–16:8.
[53] ——, "Improving Public Transit Accessibility for Blind Riders by Crowdsourcing Bus Stop Landmark Locations with Google Street View: An Extended Analysis," *ACM Trans. Access. Comput.*, vol. 6, no. 2, pp. 5:1–5:23, Mar. 2015.
[54] G. Boeing, "OSMnx: New Methods for Acquiring, Constructing, Analyzing, and Visualizing Complex Street Networks," *Computers, Environment and Urban Systems*, vol. 65, pp. 126–139, Sep. 2017, arXiv: 1611.01890.
[55] M. A. Sweden, "Street-level imagery, powered by collaboration and computer vision."
[56] G. Neuhold, T. Ollmann, S. R. Bulò, and P. Kontschieder, "The mapillary vistas dataset for semantic understanding of street scenes," in *Proceedings of the International Conference on Computer Vision (ICCV), Venice, Italy*, 2017, pp. 22–29.