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MASTER OF SCIENCE
IN ENGINEERING

3D accessibility analysis in train stations with underpasses

People with mobility impairments experience daily challenges in navigating complex, multi-level urban infrastructure, like train stations. This thesis contributes to inclusive mobility by developing a workflow that extracts multi-level navigable networks from laser scanning point clouds and by showcasing personalized wayfinding with a prototype navigation application.

Background and research aim

Navigating urban infrastructure remains demanding for many people with mobility impairments due to missing, wrong or outdated accessibility information. Generic navigation solutions fail as mobility requirements are highly diverse such as wheel-chair users, people using crutches, older adults and individuals with limited physical strength (Müller et al. 2022).

Early research investigated conceptual navigation models and crowdsourced pedestrian networks for personalized routing (Kasemsuppakorn & Karimi, 2009). Recent studies demonstrated the automatic extraction of navigable networks from laser scanning point clouds (Balado et al. 2019; Treccani et al. 2022). However, existing approaches focus on single-level environments and specific user profiles, neglecting the complexity of urban infrastructure and the diversity of mobility requirements.

This thesis addresses this gap by developing a data-driven workflow for three-dimensional accessibility analysis in multi-level train stations from laser scanning point clouds and demonstrating personalized wayfinding with a prototype navigation application.

Methodology

The network extraction workflow operates on point clouds with pre-segmented ground points and points of dynamic objects removed. The point cloud is voxelized to reduce geometric complexity and allow operation in 3d raster space. The voxels are split in obstructed, proximal and open areas based on distance to the nearest obstacle voxel, as shown in Fig. 1. Morphological skeletonization extracts from proximal voxels the centerline voxels, which results in a multi-level network following walls and obstacles. This network is simplified and additional nodes sampled from open area voxels.

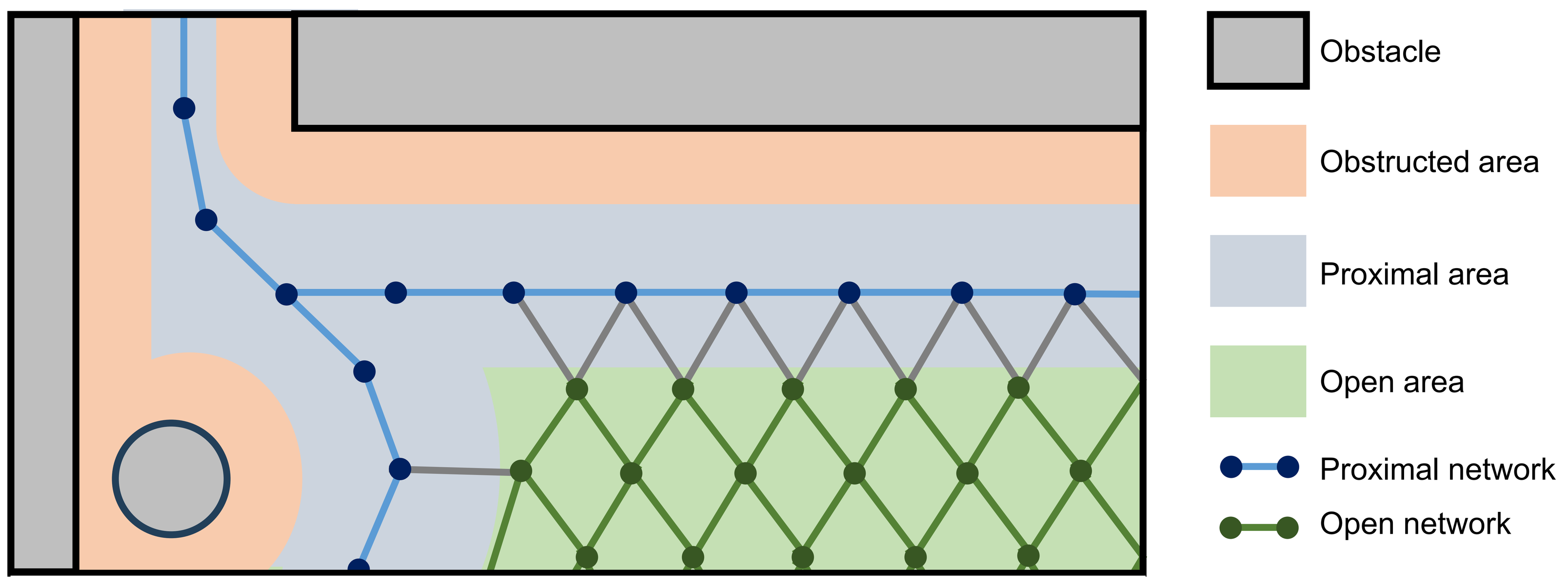

Fig. 1: Differentiation in obstructed, proximal and open voxels

This work attributed edges of the network with accessibility metrics such as longitudinal and lateral slope, width clearance, step height and surface roughness. Using these metrics, the navigation demonstrator calculates an impedance cost per edge using a personalized profile, enabling the shortest path calculation with the Dijkstra-algorithm. The demonstrator was implemented with ipywidgets for controlling the user profile and setting start and target locations.

The network extraction workflow and navigation demonstrator were applied to a laser scanning point cloud of the case study site of Madiswil train station, which was captured with Leica RTC360 and Leica BLK2Go scanners. With this data, this thesis assessed the influence of voxelization and simplification on the resulting network, analyzed the plausibility of accessibility metrics and compared the shortest path calculation with diverse mobility profiles.

Results

The main results of this work are the navigable extraction workflow and the navigation demonstrator. The output of the workflow is a dense, three-dimensional graph network that connects all navigable areas of the study site. The network avoids obstacles, follows straightly narrow passages and enables representation of vertically overlapping spaces such as platforms, stairs, ramps and underpasses. The comparison of diverse mobility profiles in the navigation demonstrator results in distinctly differing shortest paths reflecting the users' abilities. Fig. 2. shows the network and routing.

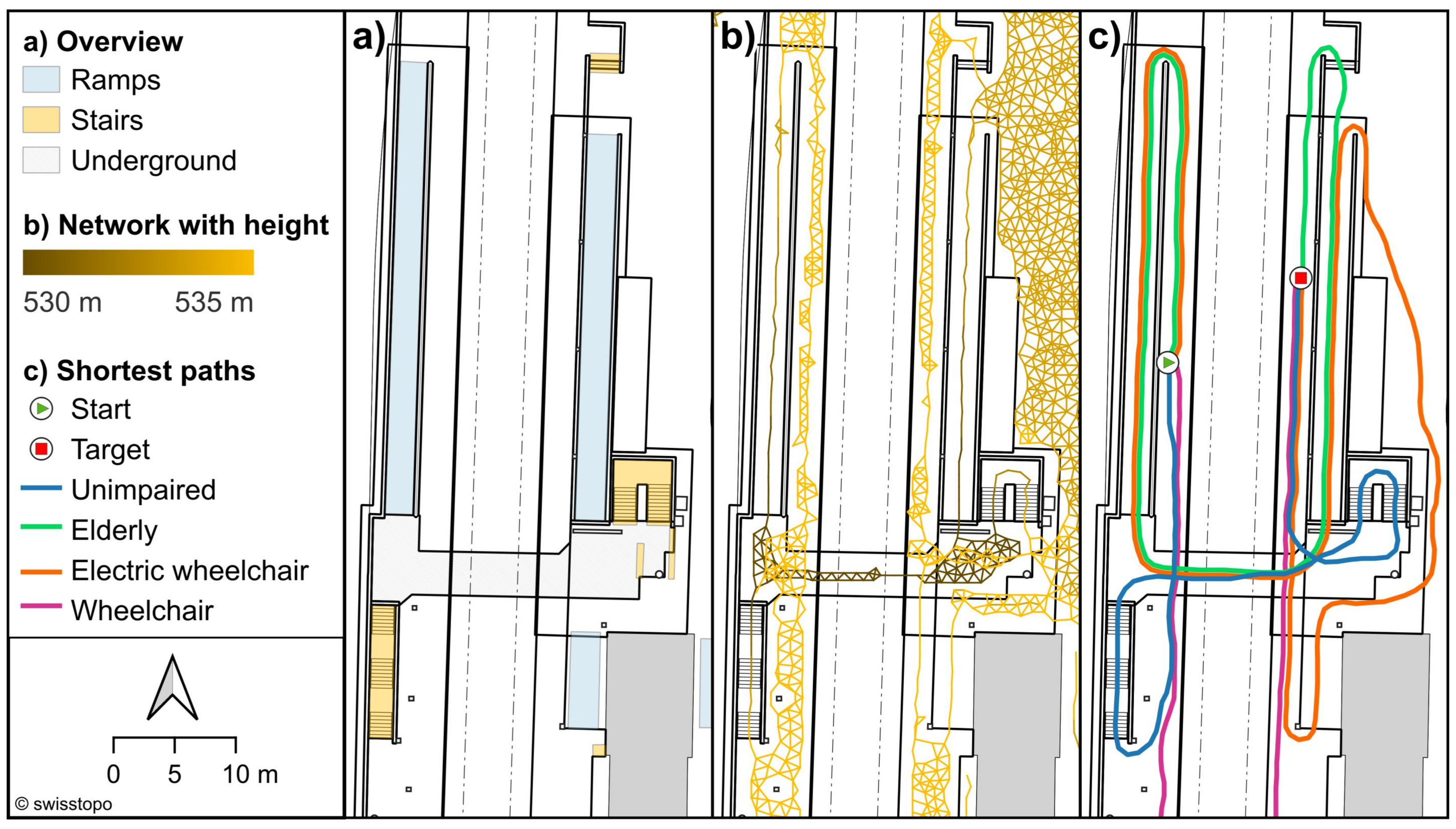

Fig. 2: Visualization of a) study site, b) extracted network, c) personalized routing

Discussion

This work successfully extends the navigable network extraction approach of Balado et al. (2019) from single-level sidewalks to complex multi-level environments. Compared to previous research, the proposed workflow is more robust and derives less complex networks while remaining user-neutral and fully data-driven. The navigation demonstrator builds on the conceptual framework of Kasemsuppakorn & Karimi (2009) and illustrates the feasibility of personalized accessibility-aware routing in multi-level urban environments.

The main limitation arises of the case study design, preventing validation across different sites and acquisition systems. Furthermore, the workflow relies on a pre-segmented point cloud which greatly influences the extracted networks quality. And the proposed personalized impedance cost formulation for calculating shortest paths represents a proof of concept and requires more development and extensive testing and validation.

Future research should evaluate the transferability of the workflow, investigate and compare robust point cloud segmentation and evaluate the accessibility metric and impedance cost calculation with reference data and through user-center studies.

Conclusion

This thesis presents a data-driven workflow for extracting multi-level navigable networks from laser scanning point clouds to support individualized accessibility analysis in complex transport environments. The results demonstrate the feasibility of personalized routing beyond single-level, single-user approaches, contributing toward more inclusive wayfinding solutions.

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Literature:

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