Designing Interactive Systems for AI Automated Walkability Assessment

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Abstract

This paper details the current stage of my PhD research, which aims to connect state-of-the-art AI models with practical applications in urban planning. My work focuses on using artificial intelligence to assess walkability, a key measure of how pedestrian-friendly an urban environment is. The research explores methods for better capturing the multifaceted nature of walkability perception by incorporating immersive experiences into the user labeling process for training datasets, as well as by applying multi-view fusion techniques to improve model understanding of urban spaces. These contributions are intended to support the development of practical tools to guide Urban Planners in designing cities that are accessible, sustainable, and truly pedestrian-friendly.

Keywords

Walkability, Deep Learning, Urban Planning, Virtual Reality, Procedural Generation, Computer Vision

1. Introduction

According to Southworth [1], walkability represents the measure of how well an urban environment supports and encourages walking in terms of comfort, pedestrian safety, reachable destinations, and aesthetics. Walkability is strongly linked to sustainability [2]: a walkable city reduces carbon footprint, represents a safe environment for all demographics and promotes economic development linking citizens to goods and services. Traditional walkability assessment methods, such as surveys [3], and walking audits are limited in scalability and efficiency [4]. This led researchers to automate the process using Computer Vision and Deep Learning techniques to generalize trained individuals' assessments of a small area to a broader urban region.

In my research, I investigate how the integration of immersive, multi-perspective experiences can improve the automated assessment of pedestrian-perceived walkability. Remote audits are often conducted on static imagery that may not fully represent the real-life pedestrian experience [5]. The idea of my research is to overcome this limitation by adding different perspectives into the user labeling and the AI model training process. From a user point of view, the creation of immersive experiences simulating real urban environments may give the users empirical insights into the walkability of a given area, leading to a more meaningful labeled dataset for AI automated assessment. Moreover, the resulting assessments can provide urban planners with more accurate, pedestrian-centered data on walkability, supporting decisions in the design or redesign of public spaces.

Key questions addressed by this doctoral work include whether immersive VR audits improve label quality over static imagery, whether they can replace walking audits efficiently, which environmental variables (e.g. sidewalk design, lighting) impact perceived walkability the most, and how VR, static, and real audits compare.

Section 2 of this paper defines the research's context by reviewing how previous literature tackled the problem of user labeling of walkability scores (Subsection 2.1), how Human Computer Interaction (HCI) has been applied in the past in the Urban Analytics field and how VR experiences have been used for Walkability (Subsection 2.2). Section 3 details the problem of walkability score prediction and

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the possible research solution. Section 4 details a preliminary research that studied how integrating a different perspective than street view imagery could enhance performances of Image Classification models, which led to the idea of incorporating different perspective into the user labeling process as well.

2. Related Works

2.1. User Labeling in Walkability Assessment

Automated walkability assessment using AI and machine learning depends on data that reflect pedestrian perception, making user labeling essential. Early approaches relied on surveys [3] and walking audits [6], which were labor-intensive and limited in scale. The adoption of street view images (SVIs) has since enabled more scalable remote audits [7], shifting user labeling to digital forms such as crowd-sourced ratings or pairwise comparisons of urban images [8, 9]. Other works have predicted subjective perceptions of urban environments from visual features in images, often using deep neural network models [10], while some have used adversarial human–machine frameworks for iterative refinement [11]. Multimodal models, such as those combining SVIs with textual prompts (e.g., CLIP), further extend labeling approaches without requiring direct manual annotations [12].

Despite these advances, most methods still rely on static, often vehicle-centered imagery that may miss important experiential factors like noise or obstacles [7, 5]. Satellite-derived data are increasingly used for aspects like street connectivity or infrastructure [13, 14], but the integration of raw satellite and street-level images for walkability assessment remains unexplored.

To address these limitations, my research proposes integrating multiple perspectives into both model training and labeling, moving beyond static imagery toward immersive, multi-viewpoint assessments of urban environments.

2.2. Human Computer Interaction and VR Experiences for Urban Analytics and Walkability

Human-Computer Interaction (HCI) has played an important role in making urban data accessible and useful for both city experts and everyday citizens. Concepts such as platform urbanism and digital civics employ digital tools and participatory technologies to involve people directly in shaping their cities [15].

Digital platforms like Social Glass help people integrate and visualize many different types of city data, making it easier for both planners and the public to understand and use information about urban life [16]. Visualization frameworks such as the Urban Toolkit provide web-based tools that allow experts and non-experts to explore and interpret urban data in intuitive ways [17].

In participatory design, city residents and other stakeholders work together with designers and planners to identify needs, shape solutions, and improve user satisfaction. Studies of new urban information services have shown that involving users throughout the design process leads to more effective and inclusive outcomes [18].

Virtual Reality (VR) has been used to provide immersive and interactive environments that can replicate or extend real urban spaces and simulate the walking experience. Solutions such as DreamWalker [19] enable users to walk along actual routes in the physical world while experiencing different virtual environments, aligning a person's physical movement with an alternative digital landscape. UrbanRama [20] integrates real-world urban data to generate digital city environments in VR, enabling users to interactively explore urban layouts, landmarks, and routes in a realistic and immersive manner.

Several studies have already analyzed the potential of VR for Walkability studies. [21] used 360° immersive videos to explore perceived walkability, demonstrating the critical role of sidewalk width and traffic direction in user evaluations. [22] applied VR visualizations of streets in Japan, Thailand, and Australia, showing that immersive VR boosts engagement and accurately reflects pedestrian perceptions. [23] conducted a stated-preference survey comparing 2D video and immersive VR scenarios, quantifying how features like greenery, lighting, and sidewalk width affect walkability perceptions. [23] validated omnidirectional video–based VR audits against field and street-view image audits, confirming that VR yields reliable subjective assessments of streetscape quality.

However, the current literature on the topic focuses more on the analysis using linear regression models and does not consider the potential of VR for conducting virtual audits that can be successfully used for AI Automatic Walkability Assessment. This research will address this gap by gather pedestrian walkability ratings from users as they navigate photo-realistic VR reconstructions of urban streets on a VR treadmill, then use those perceptual labels to train and validate deep learning models that predict walkability from street-level and satellite imagery. We will also test the possibility of using a street view dataset directly generated from the VR environment to evaluate walkability. This could be the basis for an interactive framework where the urban analyst creates a city simulation and evaluates in real-time the perceived walkability.

3. Problem and Approach

The core research challenge is to develop image classification models that can accurately predict perceived walkability just from a picture how comfortable, safe, pleasant, and interesting the depicted environment feels to pedestrians. To quantify this perception, we adopt a five-point scale proposed in the literature [24], where each interval from 1 to 5 corresponds to a distinct level of perceived walkability, ranging from very poor to excellent.

However, existing remote audit methods still rely heavily on static imagery, which often fails to capture the complex and multi-dimensional character of walkability in real urban settings. To address this limitation, we propose the development of realistic and adaptable virtual environments that enable systematic exploration of both user perception and automated assessment. This approach aims to facilitate more detailed and context-sensitive labeling, ultimately improving the quality of data used to train AI models for automated walkability assessment.

We propose the creation of a digital twin of urban areas in Virtual Reality (VR). This digital twin will enable controlled experiments with different environmental features, user perspectives, and data collection modalities, thereby supporting a deeper understanding of walkability from both a human and an AI perspective. By integrating immersive user experiences, we aim to obtain more refined labeling data for AI model training, which is critical for developing robust automated walkability assessment tools.

To realize this approach, we will combine several enabling technologies. OpenStreetMap (OSM) data will be used to reconstruct the urban layout. Houdini will provide a procedural workflow for efficient modeling of streets, buildings, and pedestrian infrastructure. CARLA [25], an open-source traffic simulator, will help us introduce dynamic elements such as vehicles and pedestrian movement. This integrated environment will support both realistic user audits, using VR interfaces like the KAT VR treadmill, and systematic data generation for training and evaluating AI models.

We expect VR to give the auditor a better grasp on how pleasant, safe, comfortable and interesting is to walk in a particular area [21, 22, 23], thus leading to more valuable walkability labels for AI training. This will allow to create an experience which is similar to on site walking audits but less costly to perform, allowing the user to visit "virtually" distant spaces in just one lab session. Moreover, we plan to create parametrizable simulations in order to evaluate how particular variables (e.g. sidewalk features, traffic, lighting, weather...) affect the walkability score, which could be the starting point for a VR framework to help urban analysts in creating pedestrian-friendly cities, supported by real-time AI Walkability Assessments. This methodology will also allow us to investigate the relationship between remote audits with street view imagery, on site audits, and virtual audits with VR to establish which setting produces the most reliable labels for AI training.

4. Preliminary Results

4.1. Walkability Assessment Considering both Street View and Satellite Perspective

As a first iteration of this work, I focused strictly on the Deep Learning part, studying a possible solution to integrate two points of view in the model training: street view and satellite pictures. For the dataset, the Sardinian cities of Cagliari, Alghero, and Sassari were selected, for a total of more than 17000 pictures.

4.1.1. Data Collection

Road networks were extracted using OSMnx, with imagery collected at midpoints of road segments via the Street View API. Each point generated two panoramic images (front and rear). Satellite images for the same coordinates were collected via Cesium ION using Unreal Engine scripting. Trained observers labeled street-level images with walkability scores from 1 to 5. For this study, satellite images were assumed to share the same labels due to resource constraints.

4.1.2. Model Setup

Five pretrained Transformer models (ViT, Swin, DeiT, Beit, DinoV2) were tested using standard metrics: accuracy, precision, recall, F1, one-off accuracy, and macro-averaged MAE (MAE^M). Models were trained on: (1) street view only, (2) dual models with late feature fusion, and (3) a custom dual-encoder combining perspectives before classification.

4.1.3. Results and Limitations

The dual-encoder model performed best overall, with Swin achieving 0.596 loss, 76.9% accuracy, 70.2% precision, 64.5% recall. 66.8% F1, 98.2% one-off and 0.39 MAE^M. However, limitations include class imbalance, static imagery, potential labeling bias from assumed equivalence across perspectives, and lack of statistical significance testing. These issues will be addressed through data augmentation, VR-based labeling, and cross-validation in future work.

4.2. Ongoing and Future Work

Current efforts focus on building a procedural virtual environment using Houdini and Unreal Engine, enabling the generation of digital streetscapes and the extraction of synthetic street view imagery within the CARLA simulator. This pipeline supports consistent data collection for AI model training and evaluation. Alongside transformer architectures, I am also testing traditional CNNs to assess model effectiveness in walkability prediction and applying data augmentation to address class imbalance.

Future work involves incorporating dynamic elements such as weather and traffic into VR simulations, and designing comparative user studies that evaluate walkability labels from immersive VR audits, static image labeling, and real-world walking audits. Evaluation metrics for comparing these approaches will be defined during the experimental design phase. Finally, I aim to test the generalizability of this framework across diverse urban contexts by adapting the pipeline to datasets from cities with varied spatial structures.

5. Current Work Status

I am actively immersed in my research journey as a first-year PhD student at the University of Cagliari. My initial focus involved an extensive academic literature review on the subjects discussed in this paper. I have also followed a PhD course in the field of Explainable AI, which could be integrated in future works on the subject. The work described here reflects my original research as a PhD candidate within the MOST project. My primary aim is to contribute meaningfully to the field by developing innovative methodologies that leverage artificial intelligence and virtual reality techniques to assess and enhance pedestrian-perceived walkability in urban environments. By integrating deep learning models with immersive VR experiences, I hope to provide urban planners and stakeholders with actionable insights for designing more accessible, sustainable, and people-friendly cities.

6. Conclusions

In this paper, I have presented the current progress and future direction of my PhD research, which aims to develop AI models applied to Urban Planning by leveraging advanced computer vision techniques and user feedback. By focusing on multi-perspective labeling and immersive VR-based audits, my work seeks to capture pedestrian-perceived walkability in a way that is both scalable and sensitive to real-world experience. This research is relevant to urban planners, local governments, public health professionals, and most importantly, the communities who use urban spaces. By providing robust, AI-driven tools for walkability assessment, the research aims to support better-informed decision-making and more inclusive urban environments.

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Declaration on Generative AI

During the preparation of this work, the author used GPT-4.1 in order to: Grammar and spelling check, content drafting, improve writing style and peer review simulation. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the publication's content.

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