On the use of a Simulation Framework for Studying Accessibility Challenges Faced by People with Disabilities in Indoor Environments

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Abstract. Navigating indoor spaces is known to be significantly challenges for individuals with mobility and sensory impairments due to the presence of physical barriers and inadequate accessible signage. Current laws and efforts have not led to meeting diverse needs of these populations. In this work we provide a brief introduction to MABLESim (Mapping for Accessible BuiLt Environments Simulator), a simulation framework for studying indoor space accessibility. MABLESim recreates digital models of indoor environments, allowing for the simulation of diverse mobility scenarios for individuals with varying abilities. MABLESim enables the analysis of critical factors important for efficient mobility in indoor spaces such as route complexity and disability characteristics. Through careful configuration of simulation parameters, MABLESim facilitates the assessment of accessibility challenges in both simple and complex indoor spaces. This framework offers a tool for designers and planners to visualize and address accessibility barriers in built environments.

Keywords: 3D modeling · accessibility · indoor navigation · simulation · algorithms.

1 Introduction

Physical obstacles within constructed environments have perpetually presented hurdles for individuals with mobility impairments. Common hindrances encompass narrow entrances, confined passageways, and irregular flooring, further exacerbated by an insufficient provision of essential amenities such as elevators, ramps, and automatic/motorized doors. The complexity of navigation within expansive indoor settings, coupled with inadequate wayfinding signage, amplifies the challenge. Particularly, individuals with sensory disabilities, such as visual impairments, encounter difficulty in utilizing conventional physical wayfinding cues, often struggling to navigate unfamiliar indoor environments, particularly those of considerable size. This challenge is frequently shared by other demographics, including older adults and individuals with cognitive or intellectual impairments.

To address issues pertaining to physical barriers, legislative measures like the Americans with Disabilities Act [1] and its subsequent amendments [4, 5] have been implemented. While such regulations have facilitated considerable advancements over the years, their impact on individuals with non-physical impairments remains limited. Moreover, for those with physical disabilities, the efficacy of these measures is constrained as compliance with stipulated requirements does not invariably ensure spaces that are genuinely accessible in essence, as usability standards are not mandated. Previous methodologies relying on manual assessments and evaluations of environments may not comprehensively encapsulate the complexities of real-world movements and interactions experienced by individuals with disabilities. Furthermore, these manual approaches are often labor-intensive and time-consuming, impeding widespread adoption. Recent endeavors have explored diverse strategies to enhance indoor accessibility for individuals with disabilities, encompassing the integration of visual cues, auditory feedback, tactile mapping, and smartphone-based wayfinding systems. However, these initiatives are hampered by their limited capacity to encompass various disability demographics on a scale substantial enough to yield actionable insights.

In this paper, we introduce the MABLESim (Mapping for Accessible BuiLt Environments Simulator) simulation framework as a scalable solution for assessing indoor space accessibility. MABLESim leverages architectural floor plans of indoor spaces to replicate key features and obstacles pivotal for studying human movements within these environments. By appropriately configuring simulation parameters, a multitude of real-world mobility scenarios can be simulated for individuals with diverse abilities, furnishing invaluable data for comprehending and enhancing the accessibility of examined spaces. As a proof of concept, we present simulation outcomes from two distinct buildings—one simple and compact, the other intricate and expansive—illustrating mobility patterns of individuals with varying abilities (including those with visual impairments, mobility impairments, and no disabilities), and elucidating insights into the accessibility and usability of each building.

2 State of the Art

In the advancement of independent indoor navigation for individuals with visual impairments, significant initiatives such as NavCog have made strides in enhancing accessibility [2]. Concurrently, Karami et al. (2019) conducted a physiological study investigating the effects of blindness on walking and jogging parameters, uncovering notable differences between blind and sighted individuals [9]. Within the domain of agent-based modeling (ABM), Fachada et al. (2015) emphasize the necessity of transparent model descriptions, exemplified by their PPHPC model, which serves as a benchmark for methodological rigor [7]. Additionally, the Flexible Space Subdivision (FSS) framework, introduced by [6], presents a comprehensive and inclusive approach to interior spaces catering to various disabilities. However, all prior human subject studies are constrained by scale and a limited number of participants, hindering a thorough investigation into the impact of various parameters.

A simulation framework tailored for indoor navigation in the context of disability offers manifold advantages that significantly contribute to enhancing accessibility in built environments. One key advantage is the detailed analysis of critical factors such as walking speed, route completion time, source-destination pairs, paths taken, likelihood of getting lost, and route difficulty, all tailored for individuals with disabilities. This comprehensive examination yields a nuanced understanding of the unique challenges faced by people with diverse disabilities, enabling the development of targeted solutions. The simulation framework serves as a valuable tool for designers and planners, providing a virtual environment to simulate and visualize potential barriers and complications that may arise in real-world scenarios.

Furthermore, the simulation framework facilitates iterative testing and refinement of accessibility solutions in a controlled digital environment prior to implementing physical changes to buildings or spaces. This iterative approach ensures that proposed modifications are effective, efficient, and genuinely enhance accessibility, thereby minimizing the need for costly and time-consuming adjustments post-implementation. The ability to customize simulations for various disability profiles adds another dimension of sophistication, enabling a granular understanding of diverse needs and preferences. Such customization ensures that resulting indoor spaces are not only compliant with accessibility standards but also genuinely user-friendly and inclusive, addressing the specific requirements of individuals with different disabilities.

3 Methodology

MABLESim leverages the Unity engine [11] to convert 2D architectural blueprints, specifically floor plans, into immersive 3D digital models, facilitating detailed simulations that closely resemble real-world environments.

A key strength of MABLESim lies in its meticulous replication of building features and structures from architectural blueprints, ensuring accurate portrayal of dimensions and placements within digital layouts. This attention to detail results in faithful representations of indoor environments, facilitating high-fidelity simulations.

Moreover, MABLESim incorporates contextual information essential for wayfinding, seamlessly integrating details such as room numbers and restroom locations into digital environments. This integration enables the study of navigation and spatial cognition within simulated environments mirroring real-world conditions.

Central to MABLESim's functionality is the integration of navigation capabilities, facilitated by a navigation mesh implemented using C++ scripts within the Unity environment. This mesh allows for intelligent pathfinding, enabling simulated entities to navigate complex indoor spaces with ease, mimicking real-world mobility patterns.

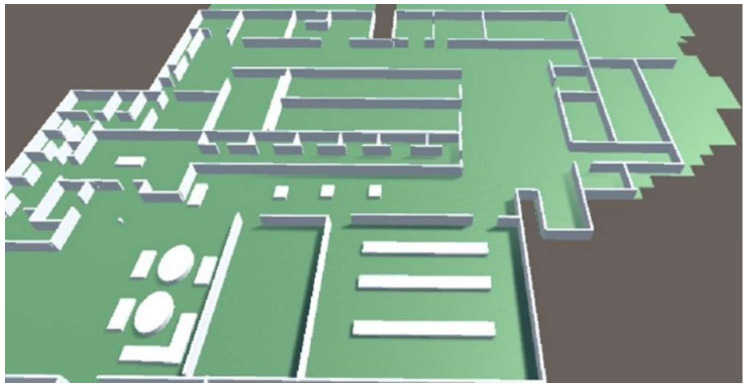


Fig. 1: Screenshot of a simulation scenario created in MABLESim.

Two key configurable parameters within MABLESim are mobility speeds and the wayfinding decision success rate (WDSR), crucial for tailoring simulations to specific scenarios and population categories. Mobility speeds can be adjusted to simulate varying movement capabilities for a population k, as shown in Table 1. The WDSR parameter influences navigation accuracy, with values informed by video traces of Persons With Disabilities (PWDs). For this work, WDSR values were set such that blind/low vision individuals chose the right branch on a route uniformly randomly, whereas all other individual with sights chose the correct path all the time. For example, for a path with a branching point with 4 potential options, those with sight impairments chose the correct path with a probability of 0.25 whereas all others chose the correct path with a probability of 1.

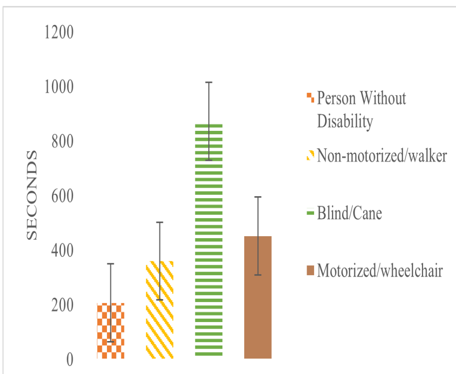
Disability Type	Speed (m/s)
No Disability	1.34
Motorized Wheelchair	0.67
Non-motorized Walker	0.98
Blind/Cane	0.78

Table 1: Mobility speeds by disability group (Sources: Sharifi et al., 2016; Alves et al.,2020)

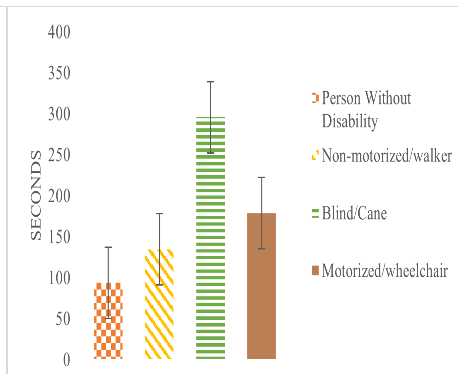
4 Results

In selecting indoor spaces to demonstrate MABLESim's utility, diverse navigational challenges were considered, including simple and complex routes exemplified by selected buildings. Of the two buildings selected, one of them (building labeled WH) was smaller with only three floors with simpler routes. The other building (labeled HST building) had a larger geographical footprint with four floors and each floor being much larger than the WH building.

Navigational performance across various population groups were evaluated using metrics such as navigation time and efficiency, providing insights into accessibility challenges. The Navigation Time metric combines the impact of route complexity and walking speed to showcase how time efficient a person is when navigating routes. The Navigation Efficiency metric is a measure of the distance walked by a person compared to the actual shortest path that existed between a source destination pair. Results shown are an average across thirty simulation runs for each disability profile. Each run comprises of a random source destination pair within the buildings, with the sources constrained to be one of of five entry points. All routes had to be at least 100 feet long to be included.



(a) WH Building



(b) HST Building

Fig. 2: WH and HST Building navigation time results

The results obtained from the simulations not only shed light on the intricate relationship between the complexity of a building and the navigational hurdles faced by its users but also underscore the pronounced impact on individuals with vision impairments. Figures 2a and 2b vividly depict how individuals with visual impairments encounter significantly prolonged navigation times, especially in more complex and expansive structures. What's noteworthy is that in simpler buildings, the discrepancy in navigation time between a visually impaired individual and someone using a motorized wheelchair is relatively minor. However, as the complexity of routes escalates, so does the magnitude of this discrepancy. Delving deeper into the analysis of route traversal efficiency, those with vision and mobility impairments cover the least distance relative to the time taken, indicative of the profound hurdles they confront in navigating built environments. For these individuals, navigational efficiency experiences a precipitous decline with the amplification of size and complexity.

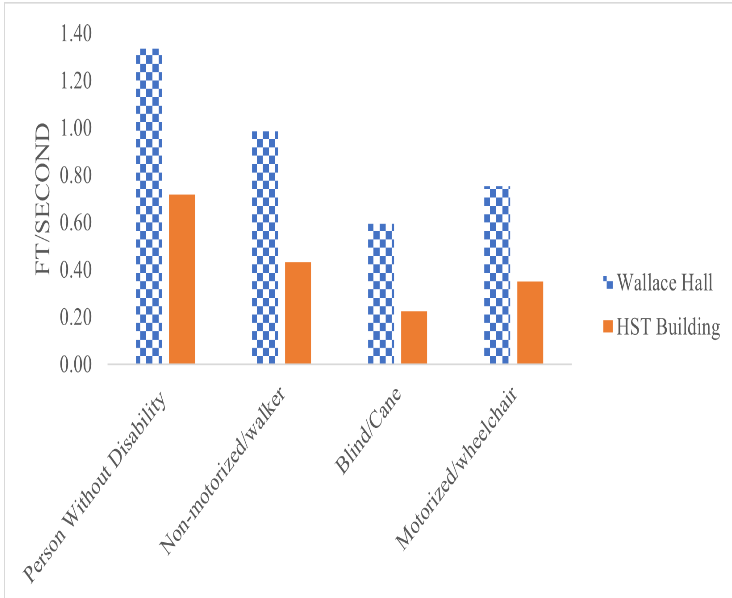


Fig. 3: WH and HST Building navigation efficiency results

5 Conclusions and Future Work

This paper introduced a simulation framework called MABLESim and how such a framework can be used to study accessibility challenges of indoor environments. Preliminary evaluation results confirm what is known about populations that face the most challenges in efficiently navigating indoor spaces. Beyond these validating insights, the simulator's principal contribution lies in its ability to serve as a versatile tool for exploring diverse configurations of built environments. Such simulation frameworks can facilitate the evaluation of emerging wayfinding technologies and their potential to enhance accessibility, offering a valuable platform for studying their real-world implications.

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