MABLESim: A Simulation Framework for Studying Accessibility Challenges for People with Disabilities within Indoor Environments

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ABSTRACT

Persons with disabilities (PWDs) face many challenges in navigating unfamiliar indoor spaces due to physical accessibility barriers, insufficient wayfinding signage, and a lack of satellite-positioning capability. Unfortunately it is not easy to study these known accessibility challenges within indoor environments due to the difficulty in collecting sufficient mobility data from PWDs who navigate such environments. This paper introduces a simulation framework called MABLESim designed to study accessibility of indoor spaces for people with disabilities (PWDs). As a novel framework, this paper presents implementation details in addition to the definition of key simulation parameters and metrics important to characterize user mobility and indoor environments. The use of MABLESim is demonstrated in two different buildings for individuals with differing mobility characteristics. As a tool to gather valuable insights, MABLESim contributes to the broader dialogue on inclusivity in built environments, offering a roadmap for creating indoor spaces that cater to the diverse needs of individuals with disabilities.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility**; **Accessibility theory, concepts and paradigms**; **Accessibility systems and tools**; • **Computing methodologies** → **Simulation evaluation**; **Simulation by animation**.

KEYWORDS

Accessibility, Wayfinding, Build Environments, Simulation, Urban Planning

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1 INTRODUCTION

Physical barriers within built environments have always posed a challenge for those with mobility impairments. Typical barriers include narrow doorways, cramped hallways, and uneven flooring, compounded by inadequate number of necessary features like elevators, ramps, and automatic/motorized doors. Complex paths within large indoor spaces coupled with inadequate wayfinding signage exacerbate the challenge. Those with a sensory disability such as visual impairments cannot conveniently utilize the typical physical wayfinding signage and find it most challenging to find their way in unfamiliar indoor environments, especially larger complex spaces. The challenge is often shared by other populations also, for example the aging population, and those with some cognitive and intellectual impairments.

To solve challenges related to physical barriers, laws such as the Americans with Disabilities Act [1] and amendments [5, 6] have been enacted. While such laws have helped make a lot of progress over the decades, they still do not make much a difference to those non-physical impairments. Even for those with physical impairments, the benefits are limited because specified requirements do not necessarily lead to spaces that are truly accessible in spirit because usability is not mandated. For example, as illustrated in Figure 1 an accessible route may be fifty times longer distance-wise than a path including a stairway. Such a a route is in theory accessible and meets current code, but practically unusable. Past work utilizing manual assessments and evaluations of spaces (for e.g., [9]) may not comprehensively capture the intricacies of real-world movements and interactions faced by individuals with disabilities. Moreover, these manual methods are often resource-intensive and time-consuming, hindering widespread implementation. Recent work has explored various methods to improve indoor accessibility for people with disabilities, including adding visual cues, auditory feedback, tactile mapping, and smartphone-based wayfinding [2, 8], but these are limited in their ability to study various disability populations at sufficient scale to provide insights for further actions.

In this paper we present the MABLESim (short for Mapping for Accessible BuiLt Environments Simulator) simulation framework as a solution for studying indoor space accessibility at scale. MABLESim can utilize architectural floor plans of any indoor space and recreate the major features and barriers important for studying movements by individuals within the space. Through proper configuration of simulation parameters, many real-world mobility scenarios can be simulated for individuals with varying abilities, providing valuable data towards understanding and acting to enhance accessibility of studied spaces. As a proof of concept, we demonstrate simulation results from two different buildings (one simpler, smaller, and another complex, larger) that show mobility patterns of persons with varying mobility characteristics (those with visual impairments, those with mobility impairments, and

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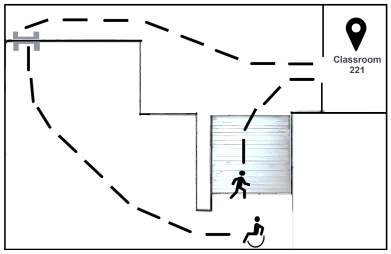


Figure 1: Example where an accessible path may be manifolds longer than a path for someone who can climb stairs. The shortest path is straight and up a few stairs, while the accessible path has to go all the way around.

those with no disabilities) and what it reveals about each building and its accessibility and usability.

This paper makes the following contributions:

(1) Presents the MABLESim simulation framework and demonstrates how indoor spaces can be simulated starting from architectural floor plans.
(2) Proposes and describes the key parameters that need to be incorporated and studied to understand accessibility and usability challenges of any simulated environment.
(3) Demonstrates how MABLESim can be used to study challenges faced by PWDs in comparison to those without disabilities.

By replicating real-world scenarios, identifying barriers, formulating inclusive strategies, and fostering awareness, MABLESim can provide a path forward towards enhanced accessibility, ultimately empowering individuals with disabilities to navigate indoor settings independently. The rest of the paper is organized as follows. Section 2 provides an overview of the wayfinding challenge for persons with disabilities, presents some of the solutions and their limitations, and the benefits of utilizing a simulation framework. Section 3 provides details about MABLESim and how it simulates any indoor environment. Section 4 provides case studies (including metrics and methods) on the application of MABLESim for two different buildings with individuals of varying mobility characteristics. Section 5 provides results of the case studies and how to draw insights from MABLESim. Section 6 concludes this paper with the presentation of future work.

2 LITERATURE SURVEY

Prior work in related areas can be separated into those focused on general wayfinding and studies incorporating more recent technology aids for wayfinding. These approaches are subsequently contrasted with a simulation-based approach as proposed in this work.

2.1 Wayfinding studies for persons with disabilities

The study of wayfinding, encompassing both indoor and outdoor navigation, is essential for understanding how individuals efficiently reach their destinations. Despite the historical aids of stars, maps, and GPS, the principles and factors influencing wayfinding remain complex and understudied, lacking a comprehensive review of the current literature [13, 21]. Originally defined by Lynch as the consistent use and organization of sensory cues from the external environment, the concept of wayfinding has evolved to denote the process of moving through space toward a spatial destination [7, 10, 17, 19, 22].

Indoor wayfinding has become increasingly crucial, addressing the distinctive complexities inherent in navigating enclosed spaces instead of outdoor environments. The intricate layouts, multiple levels, and a lack of clear visual cues indoors necessitate a more sophisticated approach, employing technologies like indoor positioning systems and augmented reality [11]. In contrast to outdoor settings abundant with landmarks and signs, indoor spaces such as shopping malls and airports demand precise navigation to prevent disorientation. Numerous studies underscore the challenges confronted by individuals with impairments in indoor spaces, highlighting the imperative for accessible interiors and a comprehensive understanding of the difficulties faced by people with disabilities in challenging surroundings [11, 16, 21]. These findings emphasize the ongoing need for research to enhance our comprehension of wayfinding, particularly in indoor environments, and to formulate effective solutions addressing the distinct challenges encountered by diverse user groups.

Navigating the built environment presents a multifaceted challenge, demanding a nuanced comprehension of signage systems and wayfinding principles. The preceding discussion on indoor wayfinding aligns with this narrative, elucidating the particular intricacies and technological solutions required for effective navigation within enclosed spaces. As emphasized in the previous section, the significance of addressing challenges in wayfinding extends to specific issues associated with signage systems. Cost constraints and a historical emphasis on digital content consumption emerge as noteworthy challenges in this domain [15, 20, 24, 27]. The integration of advanced technologies such as indoor positioning systems and augmented reality, as discussed earlier, speaks to the evolving landscape of wayfinding solutions, acknowledging the need for a comprehensive understanding of both technological advancements and traditional principles to enhance navigation in built environments.

2.2 Wayfinding through technology aids

In advancing independent indoor navigation for individuals with visual impairments, notable initiatives like GuideBeacon and NavCog have harnessed BLE beacons, enhancing accessibility [2, 8]. These technologies offer tangible solutions. Further explorations delve into crowd simulation and virtual navigation, with studies proposing innovative social-force models and spatial indexing approaches, as well as the development of engaging virtual navigation applications [3, 14, 29]. Simultaneously, Karami et al. (2019) conducted a physiological study investigating the impact of blindness on walking and jogging parameters, revealing significant differences between blind and sighted individuals [18]. In the realm of agent-based modeling (ABM), Fachada et al. (2015) underscore the importance of transparent model descriptions, with their PPHPC model serving as a benchmark for methodological rigor [12]. Additionally, the Flexible Space Subdivision (FSS) framework, proposed by Diakité and Zlatanova (2017), introduces an inclusive approach to interior spaces. It automatically identifies subspaces with specific properties to cater to diverse needs [9].

Upon examining the discussed articles, it becomes apparent that they face certain limitations. Notably, issues related to scalability and associated costs pose significant challenges, potentially limiting the broader application of the proposed solutions. Furthermore, there is a noticeable gap in the ability of these studies to fully capture the complexities of real-world scenarios, raising questions about the generalizability of their findings. Concerns also arise due to the reliance on limited sample sizes in some cases, which may impact the validity of drawing comprehensive conclusions. Additionally, the practical implementation of proposed approaches seems to be a challenge in the articles, with obstacles that could impede their adoption and integration in real-world settings. These identified limitations collectively highlight the inherent complexities involved in developing effective solutions within the scope.

2.3 Benefits of a simulation framework

A simulation framework tailored for indoor navigation in the context of disability presents multifaceted advantages that contribute significantly to the improvement of accessibility in built environments. One key benefit is the in-depth analysis of critical factors such as walking speed, route completion time, source-destination pairs, pathways taken, likelihood of getting lost, and route difficulty, all customized for individuals with disabilities. This comprehensive examination provides a nuanced understanding of the unique challenges faced by people with diverse disabilities, allowing for targeted solutions. A simulation framework can become a tool for designers and planners, offering a virtual environment to simulate and visualize potential barriers and complications that may arise in real-world scenarios. This approach enables the identification and elimination of obstacles, optimizing navigation paths and enhancing the overall user experience for individuals with disabilities.

A simulation framework such as MABLESim facilitates iterative testing and refinement of accessibility solutions in a controlled digital environment before implementing physical changes to buildings or spaces. This iterative process ensures that proposed modifications are effective, efficient, and genuinely improve accessibility, minimizing the need for costly and time-consuming adjustments after physical implementation. The ability to customize simulations for various disability profiles adds another layer of sophistication, allowing for a granular understanding of diverse needs and preferences. This customization ensures that the resulting indoor spaces are not only compliant with accessibility standards but also genuinely user-friendly and inclusive, addressing the specific requirements of different individuals with disabilities. In essence, the MABLESim simulation framework stands out for its practical utility, providing actionable insights that can directly translate into real-world improvements in indoor environments, making them more accessible and accommodating for everyone. An introduction to the MABLESim concept and limited evaluations can be found in [23]; this paper presents all the details and includes a more extensive set of evaluations.

3 THE MABLESIM SIMULATION FRAMEWORK

This section describes the MABLESim simulation framework and how any built environment of interest can be simulated to study its accessibility and usability.

3.1 Development platform

MABLESim utilizes the Unity engine [26] to transform 2D architectural designs (floor plans) into 3D digital models on which simulations can be run. Building features and structures are sculpted with similar dimensions and positioning within layouts. Any contextual information for points of interest (for e.g., room numbers, restroom/bathroom information) can be added to mimic underlying scenarios. Additional details like textures of floors and lighting are also created if such information is available.

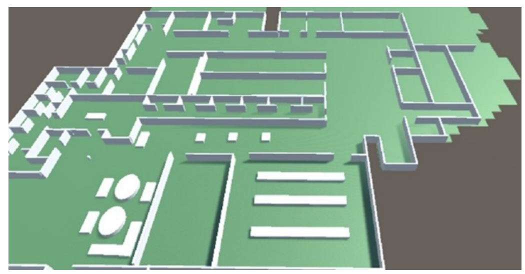


Figure 2: Screenshot of a simulation scenario created in MABLESim.

Integration of navigation functionality is a crucial aspect of utilizing MABLESim to study mobility within indoor spaces. This involves the implementation of a navigation mesh within Unity, commonly referred to as a NavMesh, using C++ scripts. The NavMesh serves as a spatial representation enabling intelligent pathfinding for characters or objects within the 3D environment. By strategically placing navigation surfaces on walking areas of the model, we ensure that characters can navigate seamlessly through the digital space.

Utilizing C++ scripts in Unity, MABLESim users can customize the behavior of characters by coding specific navigation instructions. This may involve defining waypoints, creating dynamic obstacle avoidance algorithms, or implementing interactive elements that influence the movement of virtual entities.

Figure 3 summarizes the steps taken to arrive at building's simulator starting with architectural inputs. A sample screenshot of a simulation scenario created in MABLESim is shown in Figure 2.

The physical layout of a building and its features (walking paths, elevators, staircases, ramps) impacts complexity of potential routes individual may take within that space.

3.2 Critical parameters defined within simulator

Beyond reconstruction of the physical attributes of a space, it is important to be able to simulate individuals and their potential mobility patterns. Two critical parameters that impact mobility and

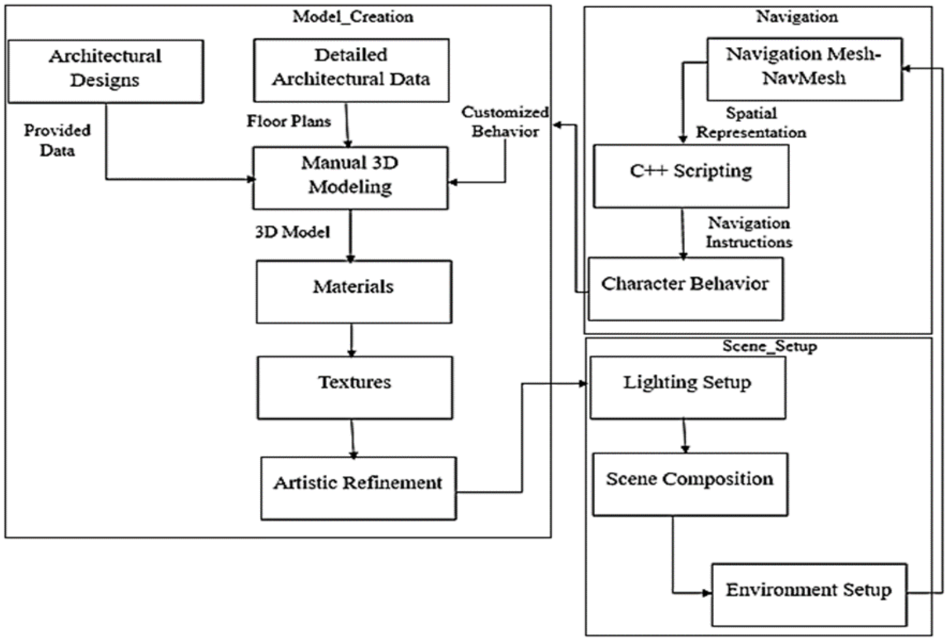


Figure 3: Flowchart depicting MABLESim process to create a simulator of a building

can be configured in MABLESim are that of mobility speeds for a specific population category, and wayfinding decision success rate.

3.2.1 Mobility speed. Mobility speed for an individual is an inherent parameter that can be set in the simulator. This parameter's value is influenced by variables such as age and fitness, type of disability (if any), and what mobility aids are being used (if any). For individuals using mobility aids such as wheelchairs, this value will correspond to speeds of those devices. For all others, this value will be their walking speeds. Because speeds of individuals can vary, we utilize an average value for this parameter on segments of any walking path.

Utilizing our prior work with PWDs, we analyzed video traces of the movement patterns of persons who wereblind (no light perception), those with low vision, and those who used motorized wheelchairs. By integrating these real-world observations with the findings of previous studies by Sharifi et al. (2016) and Alves et al. (2020) [4, 25], a characterization of average mobility speeds of PWDs in diverse indoor settings was created. The observed variations in mobility speeds, particularly between motorized and non-motorized wheelchair users, are attributed to a combination of factors, including design considerations prioritizing safety and user preferences. While every individual is likely distinct for their abilities and mobility patterns, we believe utilizing our real-world observation traces along with those of others results in a good starting point for values to use for the average mobility speed parameter; these can varied in a more fine graiend manner in future as more information is known about specific populations.

3.2.2 Wayfinding decision success rate. The second characteristic of individuals in unfamiliar indoor spaces that was felt important to incorporate into MABLESim is a parameter called wayfinding decision success rate (WDSR). This parameter captures the probability that an individual makes the correct path choice towards their destination when faced with a branching point of paths. Individuals without any disabilities will have higher WDSR than those who are blind because they can likely see wayfinding signs and/or the surrounding space, making it more probable that they make the right decision about which path will likely lead to their destination. The adequacy and accuracy of wayfinding signs within an indoor space also can be captured by this parameter. For example, if branching points of a space do not have good signage, even those who use sight will likely make many errors at those points. One can choose different WDSR values for population groups based on the adequacy of wayfinding signage for a space. WDSR is also a function of the complexity of a space. Routes with fewer branching points or fewer branches per point will have higher WDSR for everyone. Hence, WDSR must also be a function of branching complexity. For MABLESim we hence utilize the following function for WDSR for any branching point i along a route with b_i branches:

$$WDSR(i) = \min\left(1, \frac{C_k}{b_i - 1}\right), \quad b_i \geq 2, \quad C_k \geq 1,$$

where C_k is a constant associated with a specific population k and can be used to increase or decrease a population group's WDSR based on their ability to make the right choices of paths. For example, the value of C_k for a wheelchair user will be higher than a blind user because they have a higher likelihood of choosing the right path based on wayfinding signs. Note that any branching point i will have a minimum of two branches, one for the ingress path and one for the egress path, which can also be the same for a dead end. The WDSR function assumes that if no wayfinding information is available, any of the $b_i - 1$ egress paths from a branching point is equally likely to be the correct path towards a destination.

Beyond these two parameters, one can of course customize other physical characteristics of a space such as addition/deletion of existing physical accessibility features (adding or removing ramps or elevators), changing walking paths (blocking a specific path, changing surfaces), adding obstacles or furniture, among other things and study the impact on mobility patterns.

3.3 Mobility pattern simulation

The mobility pattern simulation in MABLESim combines the two parameters mobility speed, and WDSR together with the physical layout created. The crux of the simulation approach involves treating the navigation process like a branching journey, where an individual moves from a start point directly to the next branching point, and either continues successfully towards their destination, or backtracks one or more times after taking an incorrect path until they reach their desired destination. A backtracking penalty P_k is associated with each population group k and signifies the amount of distance they proceed on an incorrect path before they realize their mistake and come back to the last branching point. This penalty can be converted to a time penalty by utilizing the mobility speed s_k associated with that population group.

Algorithm 1: Enhanced Path Exploration Algorithm with Formula (Simplified)

Assume the desired destination is on a route with i branch points, including start and destination points. Initialize $i = 1$;
Move from the current point to the next branch point i at speed s_k;
while $i \leq N$ **do**
  Choose the next path from b_i options;
  if *the chosen path is on the desired route (with probability* $WDSR_i$*)* **then**
    Continue to the next branching point $i = i + 1$ at speed s_k;
  else
    Apply a backtracking penalty P_k;
    $b_i = b_i - 1$;
    Return to the branching point;

4 CASE STUDIES DEMONSTRATING USE OF MABLESIM

This section describes how MABLESim can be utilized to study accessibility of indoor spaces. To demonstrate its use, two different buildings are chosen and simulated. This section describes each of these buildings and their characteristics that are represented within MABLESim, simulated wayfinding/navigation scenarios, selection of appropriate parameter values, and metrics.

4.1 Simulation Scenario

4.1.1 Buildings. In selecting indoor spaces to demonstrate use of MABLESim, it was important to choose buildings that provide opportunities to study both simple, shorter routes, and complex, longer routes. One of the chosen buildings, called Health Sciences and Technology (HST) building characterized the larger, complex space due to its expansive layout and intricate network of pathways. The other building, Wallace Hall (WH) is a much smaller space with a more compact design. Studying these contrasting structures provides good insights into navigational challenges by PWDs and what to expect for simpler or more complex structures.

4.1.2 Navigation Task Generation. For each building, 30 random source-destination pairs were generated with the condition that they are at least 100 feet apart. This ensures that each navigational task is on a route that is not too simple. To mimic real-world scenarios, all source/start points were restricted to be one of five designated entrances of each building. Figures 4 and 5 visually depicts all floors of each of the two buildings and explicitly labels both sources and destinations generated.

4.2 Selection of appropriate values for simulation parameters

Values for the critical simulation parameters of mobility speed and WDSR have to be selected carefully to ensure that results obtained reflect real-world navigation scenarios.

4.2.1 Mobility Speed. For this paper, four population groups ($k = 1, 2, 3, 4$) were considered: individuals who are blind and cane users with no other disabilities ($k = 1$), individuals who use a motorized wheelchair with no other disabilities ($k = 2$), individuals who use a non-motorized wheelchair or walker with no other disabilities ($k = 3$), and individuals with no disabilities ($k = 4$). Mobility speed values used in this paper (shown in Table 1) were integrated insights from two pivotal studies—Sharifi et al. (2016) and Alves et al. (2020) [4, 25]. Additionally, video traces from our prior research were useful in verifying those results. Remarkably, motorized wheelchair users exhibited slower speeds compared to non-motorized counterparts, attributed to level of disability of users. Programmed speed limits in motorized devices, coupled with individual user preferences for a deliberate pace, contribute to observed variations in speeds, particularly in complex or crowded environments.

Disability Type	Speed (m/s)
Person Without Disability	1.34
Motorized/wheelchair	0.67
Non-motorized/walker	0.98
Blind/Cane	0.78

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

4.2.2 Wayfinding Decision Success Rate (WDSR). For each of the four population groups considered, we utilized video traces from our prior work of PWDs navigating indoor spaces to determine what will be good WDSR values to use for simulations. Blind users, without the benefit of any wayfinding signage, were just randomly

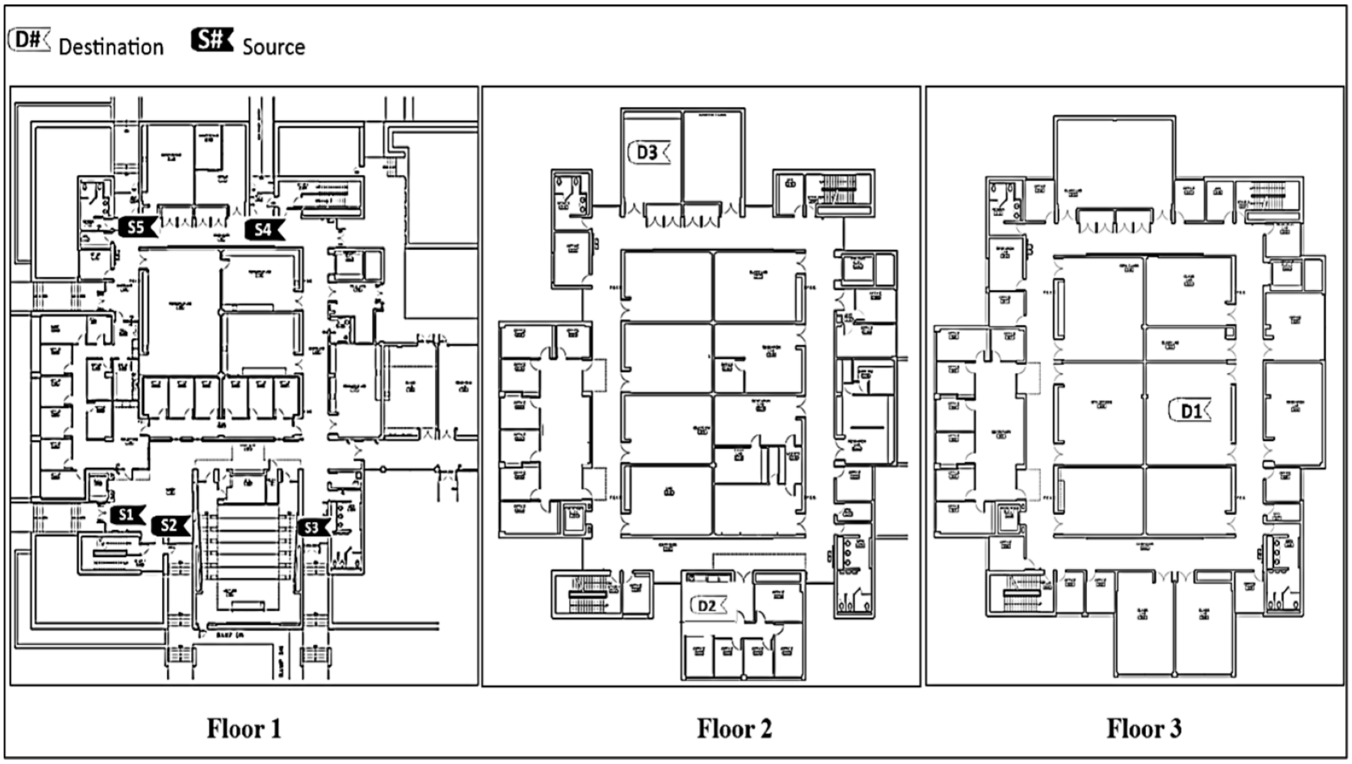


Figure 4: Wallace Hall Floor Plan with Source and Destination Labels

picking a path, and proceeding on it. We utilized $C_k = 1$ for this population. The other three groups, all with the benefit of sight, were mostly making correct path choices if wayfinding signage was adequate and they had paid attention. For the purposes of our simulation, we thus utilized $C_k = 3$, for $k = 2, 3, 4$. With the above choices, a person with the benefit of sight and wayfinding information was set to be have a WDSR three times that of someone who is blind.

With the assumption that anyone taking an incorrect path will backtrack to the previous branching point, we added a backtracking penalty value of $P_k = 12$ seconds for blind users ($k = 1$), and $P_k = 4$ seconds for users from any of the other groups, $k = 2, 3, 4$. The assumption here is the blind users have to spend additional time utilizing tactile observations from wayfinding signs to confirm if they are on the correct path.

Values of all parameters chosen can form the basis of many further studies; the values chose for this paper are for illustrative purposes based on our past observations with some PWDs.

4.3 Metrics

To assess navigational performance for the various population groups under study and utilize it as a proxy to judge accessibility challenges we utilize the following metrics:

- **Navigation time:** This metric accounts for the time taken from source to destination. Needing more time to navigate signifies the complexity of a route and/or accessibility challenges in navigating the route including any errors in choosing the correct paths at branching points.
- **Navigational efficiency:** This metric captures the ratio of average route distance across all source-destination pairs to the average time taken for navigation. A higher value indicates better performance in completing the navigation task.

5 RESULTS

The study assesses mobility performance across different groups for two distinct buildings, Wallace Hall and the HST Building, utilizing the metrics introduced in the previous section: navigation time and navigation efficiency. By examining these metrics, the study seeks to provide insights into the nuanced effects of built environment design on mobility outcomes for diverse user groups.

5.1 Navigation time results

The navigation time results within the Wallace Hall and the HST buildings quantified what is commonly known that individuals without disabilities can navigate unfamiliar indoor spaces much faster than individuals with disabilities (see Figure 6). Again as expected, individuals who are blind took the most time to navigate these unfamiliar spaces, followed by those using motorized devices such as wheelchairs. Comparing across the results from the two buildings, the more larger and complex HST building significantly increases navigation time, with blind individuals needing four times

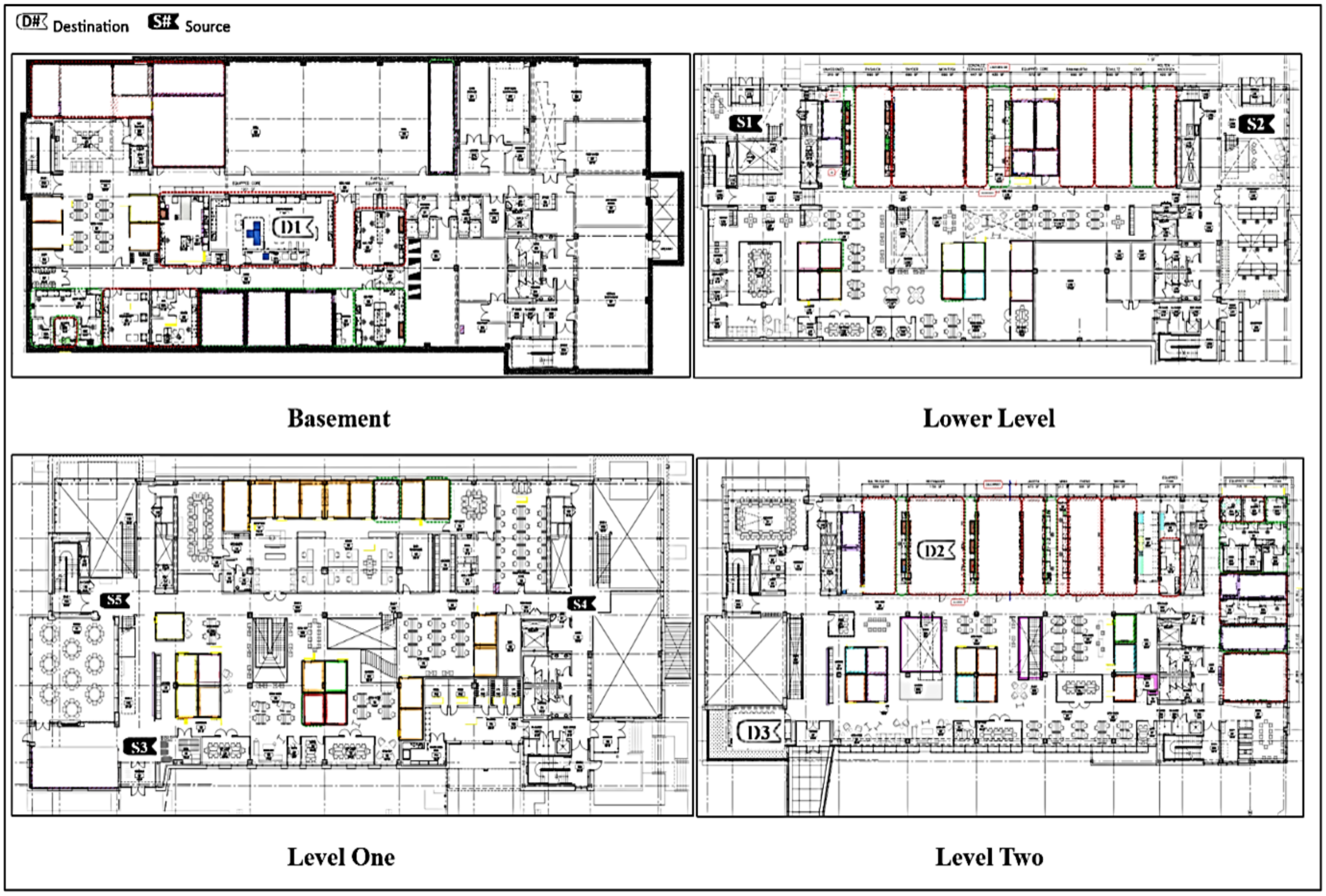


Figure 5: HST Building Floor Plan with Source and Destination Labels

as much time to reach their destinations (as compared to only three times as much for the smaller Wallace Hall building). These results confirm the magnitude of the challenge in navigating unfamiliar indoor spaces for persons with disabilities.

5.2 Navigation efficiency results

Because the HST building is larger, it is expected that routes within it will likely be longer as well. Studying navigation efficiency as opposed to navigation time allows an understanding of the impact of route complexity (number of branching points) on navigation results. As shown in Figure 7, navigation efficiency drops sharply (50% or more) when a person navigates within a complex building such as the HST compared a simpler building such as Wallace Hall. Navigation efficiency is particularly worse for those who are blind due to their difficulties in deciding the correct path at branching points.

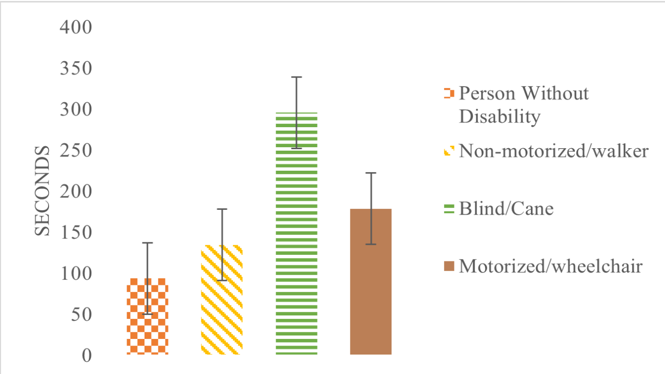
5.3 Impact of varying WDSR

For the eight combination values of C_k's as listed in Table 2 the underlying mathematically computed WDSR values are shown in Figure 8. For small branching numbers, WDSR rates are higher and they drop sharply as branching increases. Similarly, when C_k values are higher, WDSR is higher. Interesting combination of $C_k's$ happen when at least one of them is closer to 1 indicating some challenges in selecting paths.

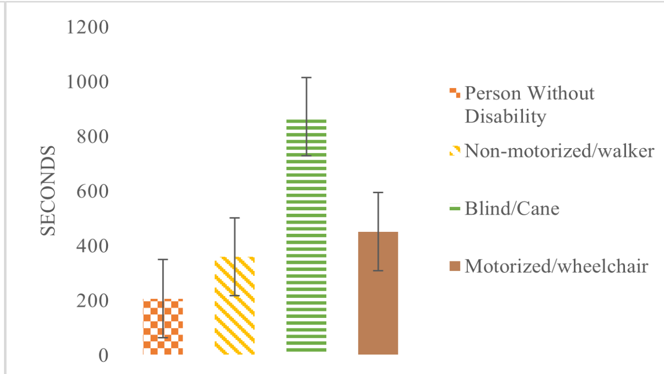
Combination	C_1	C_2	C_3	C_4
1	1	2	2	2
2	1	3	3	3
3	1	4	4	4
4	1	5	5	5
5	1	4	4	4
6	2	4	4	4
7	3	4	4	4
8	4	4	4	4

Table 2: Combinations of C_k values

Next we looked at navigation time and efficiency for both buildings for the varying WDSR values (by varying the combinations of C_k values). As can be seen in Figures 9a and 9b, higher values of C_k result in reduced navigation time and increased navigation efficiency respectively. The benefits are more pronounced for the



(a) Wallace Hall



(b) HST Building

Figure 6: Navigation time results for the two buildings

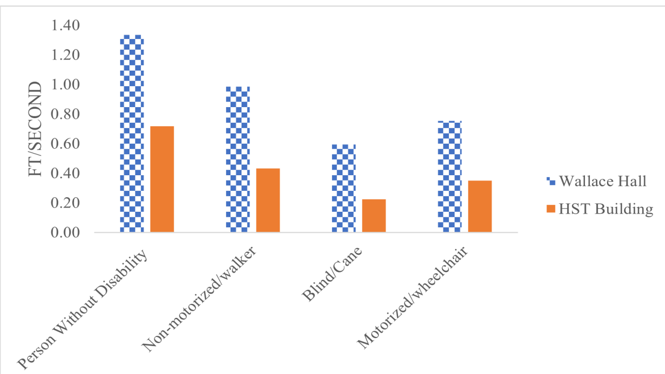


Figure 7: Navigation efficiency results for the two buildings.

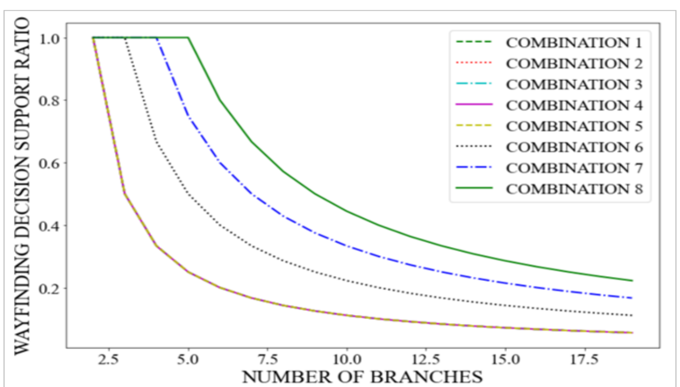


Figure 8: WDSR as a function of number of branches at a specific point on a route.

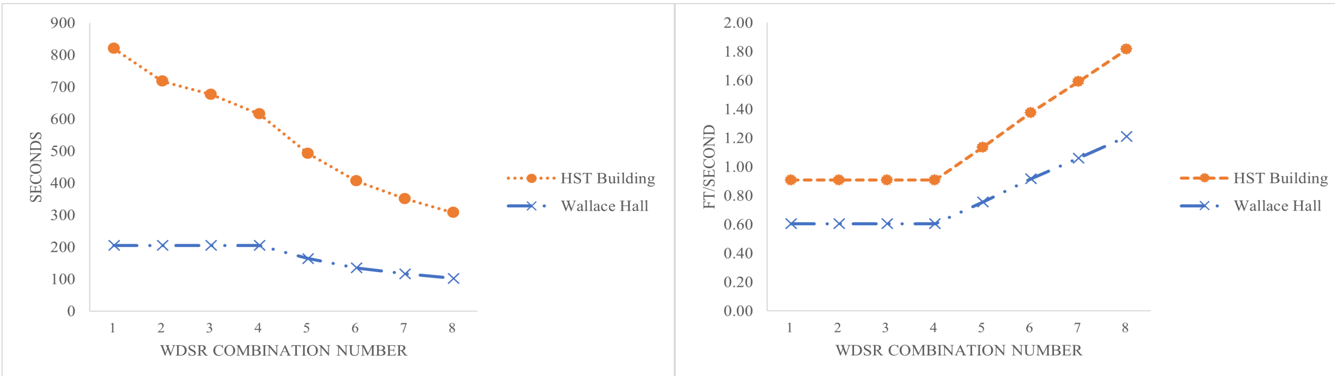
HST building due to greater complexity of routes within. This again highlights the need for improved wayfinding signage or technology within more complex buildings.

5.4 Discussion

We provide key definitions to establish a common understanding of terminology used throughout this proposal. The Indoor Navigation Simulator is a software tool developed within the Unity engine to replicate indoor navigation scenarios for training and testing purposes, aiming to enhance accessibility and usability within built environments. The Unity Engine serves as a popular real-time 3D development platform utilized for creating interactive experiences across various industries. MABLESim specifically refers to the indoor navigation simulator framework developed in this work, transforming 2D architectural designs into 3D digital models suitable for simulations and facilitating the study of mobility within indoor spaces. Accessibility is defined as the degree to which a product, device, service, or environment is available to as many people as possible, regardless of physical or cognitive abilities. Usability pertains to the ease of use and learnability of human-made objects, such as tools or software interfaces, in achieving specific goals effectively and efficiently. The Navigation Mesh (NavMesh) is a spatial representation within Unity enabling intelligent pathfinding for characters or objects within a 3D environment, facilitating seamless navigation through digital spaces. Disabilities (PWDs) refer to persons with disabilities, including those with physical, sensory, cognitive, or mental health impairments that may hinder their full and effective participation in society on an equal basis with others. Simulation Parameters encompass variables and settings within the simulator controlling aspects such as environment layout, character behavior, and interaction mechanics to simulate realistic indoor navigation scenarios.

5.5 Limitations

Through this work, we have only scratched the surface of considering various built environment types, sizes and layouts. Studying those can offer much richer insights into accessibility and usability challenges. The use of an average mobility speed for each population considered is limiting; individual profiles of mobility within each disability group should be created to capture variances within populations better. The current simulation model assumes each individual will come back to the branching point if they make a



(a) Navigation Time **(b) Navigation Efficiency**

Figure 9: Navigation time and efficiency as WDSR values vary.

mistake in choosing the correct forward path; this should be modified to allow individuals to go off onto incorrect paths that may lead back to the correct paths through longer routes, and consider rerouting options. Finally, we acknowledge that simulating disability, and simulating mobility challenges posed by disabilities will never fully capture the range and interplay of physical and psychosocial aspects involved; the simulator should only be used to gather initial insights (at scale) before resorting to smaller-scale human subject studies for further validation and improvements.

6 CONCLUSION AND FUTURE WORK

This paper presented a simulation framework called MABLESim that allows an in depth study of navigation and wayfinding performance across diverse groups of individuals with disabilities. Capabilities of the simulator, critical parameters, and important metrics were described. A demonstration of the use of the simulator for wayfinding by four different groups (including one without disability) was presented through case studies of two different buildings. Results validated existing knowledge about how wayfinding can be a challenge in larger complex buildings, and provided tools for more fine grained studies on the impact of wayfinding signage and technology on making buildings more easy to navigate.

This work not only contributes to the advancement of simulation methodologies, but also provides practical insights for designing inclusive and accessible environments in the context of modern architecture and urban planning. The ramifications of this work extends across a spectrum of fields, including but not limited to policymaking, urban planning, environmental management, and socio-economic development.

Future work will include additional studies with varying mobility speeds for different groups, allowing for more advanced capabilities like re-routing, quantifying decision success rates of existing wayfinding signage and technology, and taking advantage of 3D representation capabilities.

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