Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

School of Computer Science and Statistics

Using Digital Twin Cities to Investigate Older Walkability in Dublin

Christopher Maher
[redacted]

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Supervisor: Siobhán Clarke

A Final Year Project submitted in partial fulfilment of the requirements for the degree of MAI (Computer Engineering)

Declaration

I hereby declare that this project is entirely my own work and that it has not been submitted as an exercise for a degree at this or any other university.

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Abstract

Ever since the mass production of automobiles our cities have become less pedestrian friendly to cater for vehicle transport. Paths and footways are reduced or removed to build more roads to fulfil the ever-increasing demand for car infrastructure. This has a negative impact on the walkability of a city, especially for older people. This can lead to negative consequences such as isolation and a reduction in physical activity. This study explores the use of Digital Twin Cities and their suitability for predicting walkability concerns.

This study focuses on kerb heights around Dublin and how they can prove to be a challenge for some older people. Previous studies on Walkability have investigated either macro level Walkability such as walking distance to public amenities or micro features such as the impact of tactile pavements on the gait of older people. This study uses a Digital Twin City model of Dublin to investigate kerb height, a micro level feature, on a macro scale test.

To investigate the walkability concerns, a simulation environment was created using the Unity game engine and the Digital Twin of Dublin. In the simulations, agents are created to walk around the Digital Twin environment. If agents encounter steps up or down with a height greater than that of the agent's step height it results in a fall. This agent step height is tuned based on the demographic agility being simulated, Older Agents having progressively less agility. The falls are recorded and displayed as a heatmap which visualises the areas of most concern. Multiple simulations were run for Able bodied agents as a baseline and then progressively Older Agents to investigate the different areas of concern for the different demographics. Finally, the heatmap data to inform modifications of the Digital Twin to improve walkability and evaluated these improvements.

This study found that Walkability concerns can be effectively evaluated using the Digital Twin City. It was also revealed that the current 3D model lacks sufficient resolution to capture all Walkability concerns, specifically with regards to step height and level change resolutions at crossings. In fact, the heat maps accurately predicted the points where sloped footways of dished kerbs are located. The inclusion of dished kerb details on future Digital Twin models will facilitate the performance of a more detailed future study.

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I'd like to thank my Supervisor for all the assistance and recommendations.

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And I'd like to thank my parents for putting up with me and always keeping me focused on the end goal.

Contents

Terminology

Digital twin model

I am using the 3D Model of the Dublin Docklands area from 3D Data Hack Dublin [1]. This model, provided as a tool for simulation and visualisation, provides me with accurate special data including location of paths and curb heights. I will use this as the location in which to run my simulations.

Walkability

"Walkability is a measure of the effectiveness of community design in promoting walking and bicycling as alternatives to driving cars to reach shopping, schools, and other common destinations." – Rattan et al. [2]

Agents

In the context of simulation an Agent is an entity that has certain behaviours which guide its interaction with its environment. Specific to my simulation an Agent represents a person from one of the test demographics, either an able-bodied person or an older person, and will have behaviours that correspond such how the height of steps they can ascend. Many of these agents will be used in each simulation to collect results.

Agent Agility

This is the measure of Agent what height of step will cause an agent to fall, encountering steps of larger magnitude than this value will trigger a fall. (This agent step height is tuned based on the demographic agility being simulated)

Agent Optimism

This is the measure of what height of step agents will attempt to traverse.

Heatmap

"A heatmap is a data visualization technique that shows magnitude of a phenomenon as color in two dimensions." - Wikipedia [3]
I use a custom heatmap to represent the incidence and location of falls resulting from the simulation, this information is then used to inform conclusions and highlight locations that would most benefit from any improvements.

Unity

Unity is a Game development engine [4] that provides tools for building a wide variety of games or simulations, the latter being the use case in this study. Unity is useful for me as I can load up a scene with the Digital Twin Dublin model and then create the Agents to interact with the Digital Twin.

Scripts

In unity the way to control the behaviour of entity by use of scripts. These scripts define what happens when an entity is created and then on every frame the it exists in the scene. Using these I can initialise arrays, create new objects, set the behaviour of my agents and control advanced constructs such as the Heatmap.

Unity Navigation

My agents need to be able to find their way around the Digital Twin model, so unity provides a Navigation tool. This is comprised of multiple parts;

The Navigation Mesh (NavMesh) represents the area where an Agent can move. The NavMesh is created as part of the scene and the area where the agent can move is determined by the properties of the type of Agent I want to investigate. Note the NavMesh is not dynamic and must be baked into the scene before the simulation is running.

The NavMesh Agent is a component that when added to an Agent enables pathfinding on the NavMesh. An Agent with an attached NavMesh Agent will travel through the scene along the NavMesh towards its destination.

1 Introduction

While the rise of motorisation has brought with it many advantages, it has changed the focus of urban planning to the detriment of pedestrians. Ann Forsyth discusses this shift in transport restricting the movement of pedestrians[5]. A reduction in pedestrian infrastructure to make way for cars makes a city less walkable overall, making travelling difficult for people without cars or access to public transport.

The aim of the study is to explore and test the viability of using a Digital Twin City model of Dublin to investigate and predict Walkability concerns. It also looks at using the model to investigate kerb heights and their impact on Walkability for Older people. This will provide some idea if there are any problem and highlights areas where more pedestrian infrastructure is needed.

1.1 The Impact of Walkability

Walkability has a great impact on how we live our lives.

It can affect house prices with studies showing significant increase in house value when going from average to above average Walk Scores, with increases ranging from $4,000 to $34,000 [6]. This especially relevant to Dublin as the larger increases were observed in denser, urban areas.

Regarding transportation 10-20% journeys don't involve motorized transport and most of the journeys that do start or end with a walk such as; walking to transit, to and from parked cars, and within airport terminals, "Improving non-motorized is often one of the most effective ways of improving motorized transport." [7]

Walkability also has health and wellbeing benefits. Lee et al.[8] find that physical activity is associated with decreased stroke risk in men, men who walk 20km per week or more significantly reduced the risk of stroke, even as the only source so physical activity, showing the clear benefits of staying active on one's health. People living in walkable neighbourhoods are more likely to interact within their community, know their neighbours and be more trusting of others when compared with those living in car-oriented suburbs [9].

Walkable pedestrian environments also support socialisation and recreation so maintaining and investing in pedestrian spaces provides community benefit [7].

1.2 Walkability for Older People

Walking is hugely important for older people. Oriol Marquet et al. investigate and find that walkable neighbourhoods/urban areas contribute to a much greater degree of mobility in older people [10]. In areas where this is not the case this can lead to Immobility and Isolation in older people. Both are serious issues - the reduced physical activity from the lack of mobility is rated by the W.H.O. as “one of the leading risk factors for death worldwide” [11] and the isolation can cause depression. Ethan M. Burke et al. [12] cite high depression prevalence among older people and the link between depression and greater risk of disease & mortality then conduct a study which showing a significant association between neighbourhood walkability and depression in older men.

2 Literature Review

2.1 Studies on Walkability

One of the areas I investigated was the difference in experience that older people have regarding walkability. Innocuous things such as the tactile pavements for the vision impaired used around street crossings can cause difficulty for older people. [13] S.B. Thies et al. studied the effect of tactile pavements and ramps on walking control. For me the study illustrated that the physical properties of pavements can disrupt the walking rhythm or cause falls in older people which can be a serious health risk.

Crossing the road is a different challenge for older people as well. Oxley et al. show the differences between demographics in judging safe gaps to cross roads highlighting older people needing more time and weighing distance over speed of approaching vehicles leading to a higher degree of risk when crossing a road [14], Similarly - Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task[15]. Older people Have trouble judging when is a safe time to cross the road, both due to reduced mobility and trouble accurately gauging the speed of oncoming vehicles. I will be looking into the road crossings in Dublin to investigate if these need to be improved in the pursuit of walkability too.

National Seniors Australia [16] survey their members to investigate the factors limiting their public transport use. The study found that for 16% difficulty climbing steps was the limiting factor and for 19% difficulty walking. 60% of respondents agreed that footpaths urgently need upgrading.

It is also possible to conduct surveys without asking participants. Using video graphic surveys, Avinash et al. [17] analysed pedestrian safety margin at crosswalks from observation. They found that, similar to the findings of Oxley et al.[14], older people encounter more risk when crossing than younger pedestrians, showing this as a suitable method for walkability investigation. Given that kerbs are often an interface between paths and roads, inappropriate kerbs may further increase risk in crossing, as inconsistent path features may cause falls in the road[13].

[18] A Walkability case study in Brazil and found that “Sidewalk Geometry” or the physical properties of the paths such as slope or with impact individuals with reduced mobility to a greater degree than able-bodied counterparts.

These studies use different forms of surveys, population participation and lengthy data entry. It may be possible to simulation to accelerate investigations and facilitate more research into Walkability.

2.2 Simulations modelling Walkability

Majic et al. [19] develop new simulation tools to more effectively measure and map walkability access around a city, also noted that distance is not only factor, micro features of the paths and social reasons affect walkability. Badland et al. [20] show it is possible to use Agents interacting in an environment to model Walkability.

These studies use are tools to simulate walkability at increased speed and convivence as compared to physical surveys. They are limited in the features they can investigate however as the 2D path data use can only investigate macro features such as distance to nearby amenities.

This is where the Digital Twin City model is interesting, a 3d model of a city could facilitate more investigations. This study explores that buy using a Digital Twin City model of Dublin to investigate kerb height, a micro level feature, on a macro scale test.

3 Methodology

3.1 Brief Overview

To detect the areas of walkability concerns in the city I have agents traversing the model to randomly determined locations and if an agent steps up or down a height greater than that of the Agent Agility it will count as a fall. Each time one of these agents falls over the location is recorded. There is a grid that expands over the testing space which divides the scene into small cells. When a fall event is processed the value in the cell corresponding to the location is incremented. This grid can then be rendered on screen as the heatmap to visualise the areas where the most falls are occurring. This data can then be used to inform where improvements need to be made in the city.

3.2 Pathfinding

To enable the Agents to move around the scene autonomously I need to provide them with a pathfinding solution, below are the ones I explored.

Default Unity Navigation

Unity provides an implementation out of the box, creating a Navigation Mesh (NavMesh) which represents the area where an Agent can move. The also provided NavMeshAgent components can then be added to Agents to enable pathfinding on the generated NavMesh.

To reduce the complexity, a NavMesh only approximate vertical position. This would prevent any accurate investigation into a micro scale feature such as kerb height to compensate Unity Navigation can also generate a Height Mesh which complements a NavMesh with the accurate height data needed.

A limitation is this choice is that only one NavMesh can be generated per scene and as the NavMesh is tied to the Agent parameters only one Agent type can be tested in a simulation. However, this can be managed by performing more tests to get coverage of all the Agent types.

Homebrew Pathfinding

One option is implementing my own pathfinding method. This would have the advantage of being fully flexible to my simulation giving me the freedom to test all kinds of situations and features. I started my refreshing myself on algorithms I'd experienced previously in my course and settled on the A* Algorithm as a baseline (A* is a best first search which uses a heuristic to guide it search). Investigating further it became clear that a new implementation of a pathfinding would be an unacceptable time sink. Firstly, developing a pathfinding system for a 3d space rather than a graph system is vastly more complex, involving converting the 3d space to a construct that an algorithm can understand. Secondly even with all of this work the implementation would still be subject to similar limitations of off the shelf solutions provided by unity.

Unity Navigation component workflow

This is similar to the default unity navigation with a few clever upgrades, it supports building multiple navigation meshes into the scene for a variety of different agents and is designed in a more modular fashion. This would be handy for running simulations with agents of different parameters at the same time.
Unfortunately, this solution is missing support for generating Height Meshes which are crucial for precise vertical positioning of Agent. Without this is become a significant challenge for agents to detect falls as the.

Chosen Solution

Considering the pros and cons of each Solution I decided to use the default Unity Navigation for its convivence and essential feature regarding the accurate Height Mesh.

3.3 Step Detection

For my analysis to work I need two key features, firstly for agents to encounter steps that will cause a fall and secondly to detect said fall. With unity navigation it is usually all or nothing, agents will not consider routes with steps higher than the 'step height' parameter defined when making the NavMesh. This makes finding walkability concerns more complex as it is unclear whether the areas that the agents don't venture into are due to walkability concerns or optimal pathfinding, requiring additional work to separate those cases. To solve this, I split up the concept of agent step height into two different features, Agent Optimism and Agent Agility. Agent Optimism defines the routes that the Agent will consider taking and used to create the NavMesh for all the agents in each test. Agent Agility is used to check what counts as a fall for an agent, if they take a step larger than their Agility it will register as a fall - this is dynamic and is set/chosen whenever a new agent is created.

Now that that Agents have the potential to walk over problem spots, I need a way of detecting them. This is achieved by saving the 3D coordinates an Agent each frame, then on the next frame comparing them with the current coordinates of the agent. A delta in the Y-coordinates indicate a change in height or a step. If this delta is greater than that of the Agent’s Agility a fall is recorded at this position.

3.4 Sandbox Area

The Digital Twin City model of Dublin is large and resource intensive so to accelerate development in the early stages I created a small sandbox environment. This allowed me to more responsively test new scripts and parameters and gather rapid results.
In the environment I created sample features that I want to investigate in the larger model such as walls, steps and destinations. Below is an image from the sandbox environment. The red cubes are the Agents, the yellow capsules are the destinations for the Agents, the blue shapes are walls and the white shapes are the 'kerbs' that I use for testing the Agent's step detection.

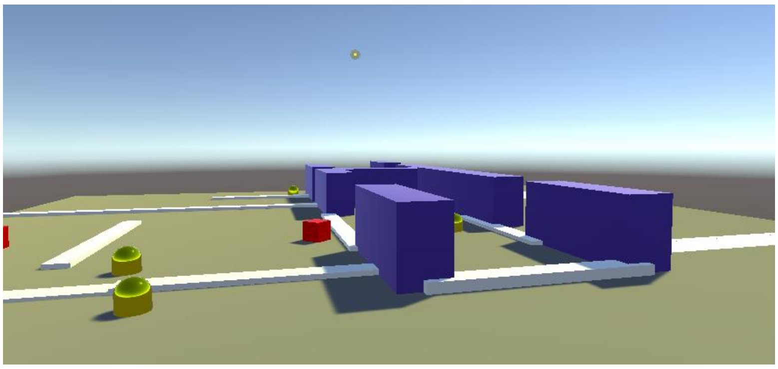


Figure 3.1 Sandbox environment

3.5 Heatmap

Now that the data for the locations of falls exists it is time to visualise it for human readability. I choose a heatmap for the purpose due to its high suitability for reprinting density of events in two dimensions. The heatmap is a combination of a grid that spans over an area, each cell in the grid representing the number of falls in that location, and a visual mesh of triangles which are textured with the below colour scale according to the values in corresponding grid cell.

Figure 3.2 Heatmap colour scale

This produces a clear visual representation of where Agents fall in an environment.

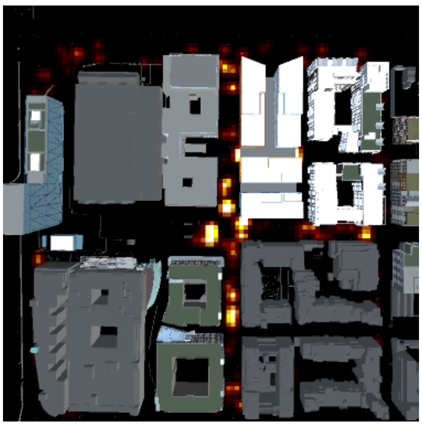


Figure 3.3 Heatmap Visualization of falls

3.6 Building NavMesh

For my Agents to path find using Unity navigation I need to generate or 'bake' the NavMesh into the scene. The NavMesh uses the properties of the Agent, in this case Agent Optimism, to create the walkable areas where pathfinding can occur. Accuracy is important for the NavMesh as all the results and conclusions are based off accurate pathfinding. When baking the NavMesh I can turn how the different terrain interacts the generation. It is possible to set a higher cost for certain types of terrain so I set paths to the default setting and the roads I set higher to encourage the Agents staying off the roads.

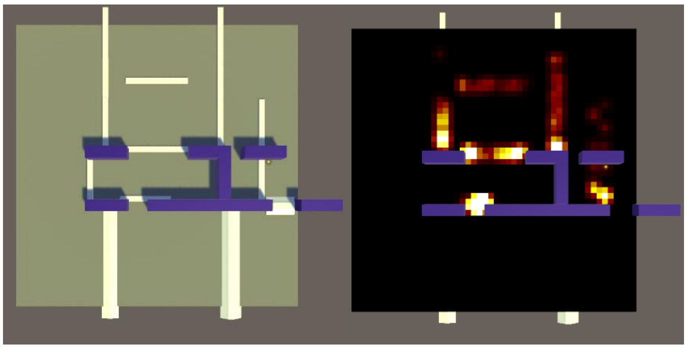
3.7 Simulation

To gather meaningful results, I needed a way of running full simulations of many agents in the environment with a range of parameters and testing conditions. For this I created the AgentsController object.
The AgentsController creates an Agent and a Target as a Pair, sets their parameters and places them in the scene within the testing area then sets the Target as the Agent's destination. It repeats this up to the desired total of Agents, then starts a timer for the simulation. Once the timer has elapsed the simulation is stopped, the Agent-Target pairs are removed and the heatmap of that simulations fall data is displayed.

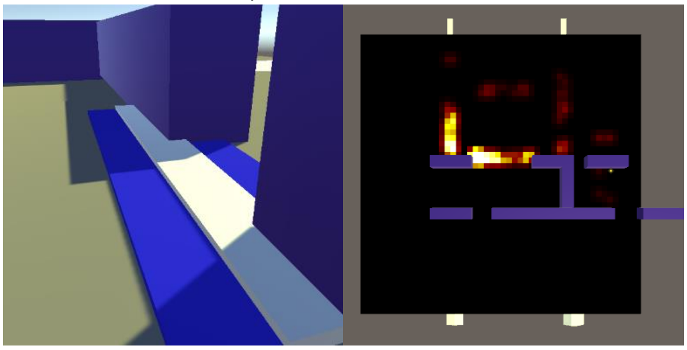
In these longer tests Agents may reach their targets before the simulation timer so rather than leave the Agent idle the Targets reposition themselves when the agent reaches them or after 60 seconds whichever is sooner. These keeps the simulation flowing.

Sandbox simulation

To test if my simulations worked as expected I trailed them in the sandbox environment, below is the sandbox from above and then the heatmap from a completed simulation. Simulation of the agents successfully provides the heatmap with data to visualise the difficult steps.



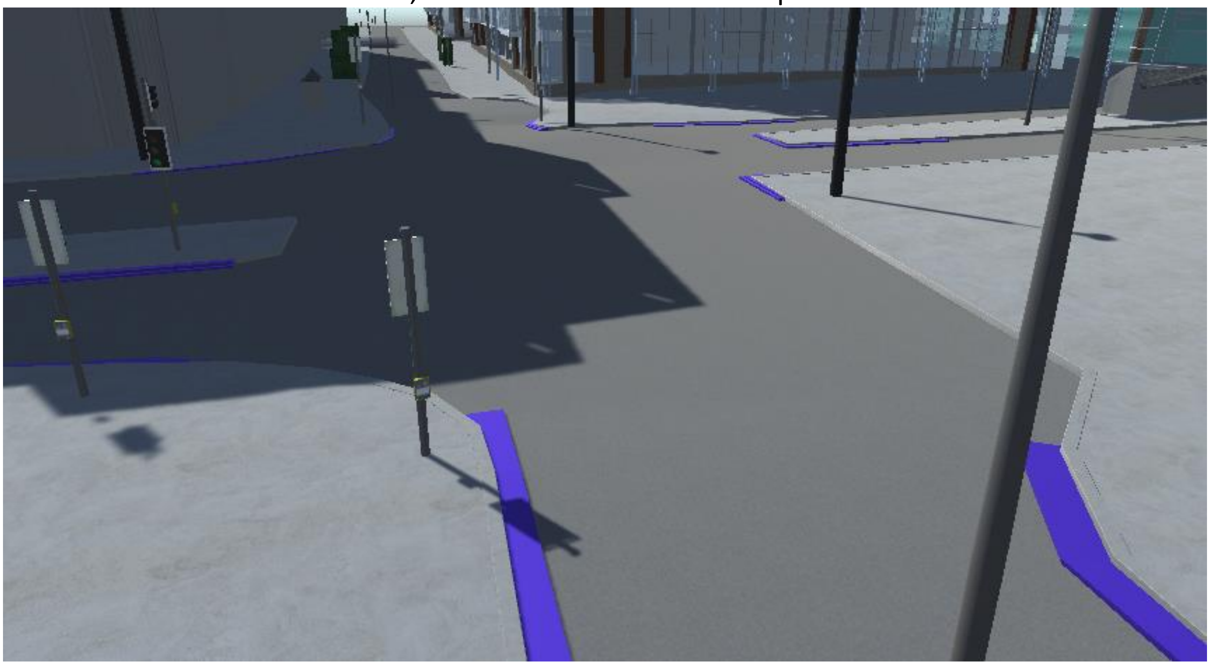
As an additional test I modified the sandbox to address the significant fall hotspot in the bottom of the area, below shows the modification and the new heatmap.



The heatmap shows a clear benefit in adding extra steps to reduce falls in an area.

3.7 Modifying Model

With results from the tests Investigating the Walkability with the Digital Twin I can use the heatmaps to identify problem spots that could be improved to aid Walkability. One area of interest in many of the simulations was the crossroads in the centre on the test area with a high concentration of falls. To address the problem in this area at the concentration points I added extra steps to help Agents encounter the high kerb with less difficulty. The modifications are shown below, blue indicates the extra steps.



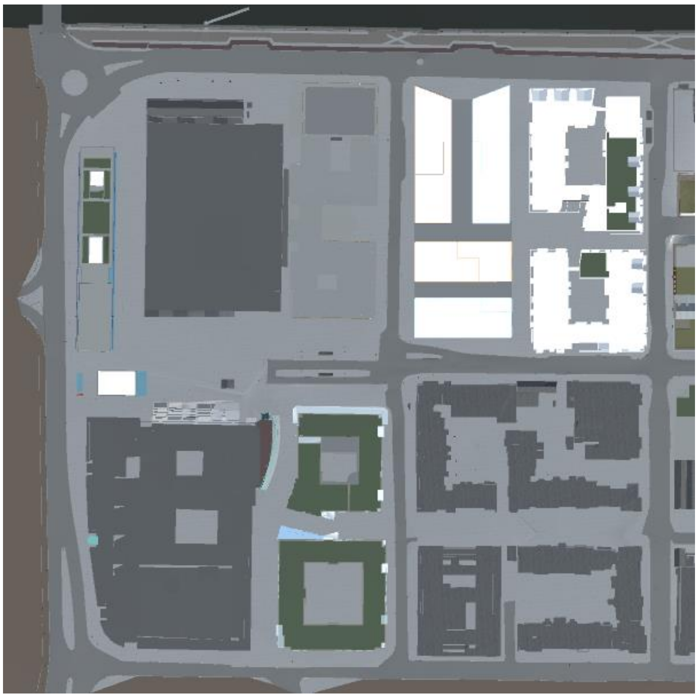
4 Results

4.1 Testing methodology

To maintain consistency and comparability I have standardised the test runs. Each test has 3 simulations runs and each simulation contains 50 Agents running for a total of 300 seconds. To start the agent-target pairs are created in the scene and then the simulation is started. After the simulation is complete the agent-target pairs are removed and the resulting heatmap is displayed. This means I can run simulations for a range of different Agent Agilities and make valid conclusions from comparing the heatmaps. To account for outliers each test will consist of multiple simulations.

For my simulations based my parameters on the standard kerb height in Ireland of 125mm, reducing to 60mm for areas of high pedestrian traffic [Recommendations for site development works for housing areas] [21][Good Practice Guidelines on Accessibility of Streetscapes] [22][Design Manual for Urban Roads and Streets] [23]

The area used for all following tests is shown below, it was chosen as it has interesting features to investigate including the complicated crossroads in the centre including mid island crossing points.



4.2 Test Parameters

Able bodied Agent test
Agent Optimism 200mm
Agent Agility 175mm +-25mm
This test serves as baseline for which other tests can be compared against. The parameters are setup such that all Agents have an Agility greater than the standard kerb height. Results from this test will highlight non-compliant kerb heights in the test area.

Older Agent test 1A
Agent Optimism 200mm
Agent Agility 125mm +-25mm
This test investigates how reduced Agility impacts Agent fall rate. Agility is set such that half of the agents in the test will have an Agility less than the standard kerb height.

Older Agent test 2A
Agent Optimism 125mm
Agent Agility 100mm +-25mm
This test investigates further reduced Agility in addition to reduced Agent Optimism on Agent fall rates. Agility is set such that all the agents in the test will have an Agility equal to or less than the standard kerb height, many of which with only slightly higher Agility than the reduced kerb height of 60mm. Optimism is set to standard kerb height reflect a more realistic value given reduced Agility.

Older Agent test 1B
Agent Optimism 200mm
Agent Agility 125mm +-25mm

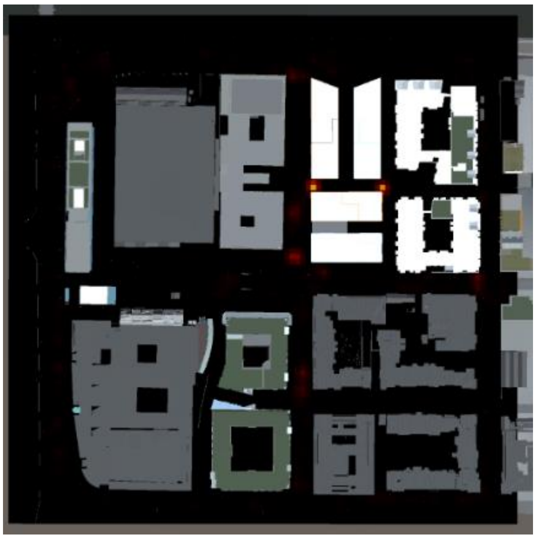
This test investigates the impact of the Digital Twin model modifications on Agent fall rates compared with the results in test 1A. The Digital Twin model modified to include Walkability Aids in hotspots Identified in previous tests.

Older Agent test 2B
Agent Optimism 125mm
Agent Agility 100mm +-25mm
This test investigates the impact of the Digital Twin model modifications on Agent fall rates compared with the results in test 2A. The Digital Twin model modified to include Walkability Aids in hotspots Identified in previous tests.

4.3 Test Heatmaps

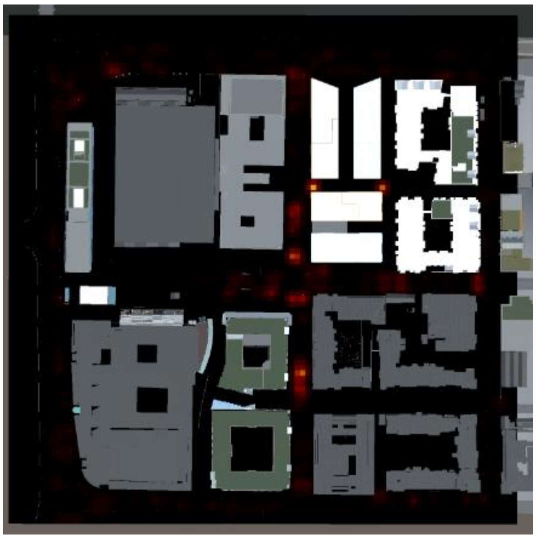
Able bodied Agent test

This is the first test and serves as a baseline investigating Agents not expected to record many falls. Even so the heatmaps show that falls are occurring around the map. Especially in figure 4.2 we can see two hotspots at either end of a pedestrian walkway between buildings.



Older Agent test 1A

We can see from these heatmaps that a reduction in Agent Agility Leads to a greater incidence in falls, especially around road crossings as this is where the agents will likely interact with the most kerbs. It is interesting to see that the hot points in the heatmap often align with the city blocks.

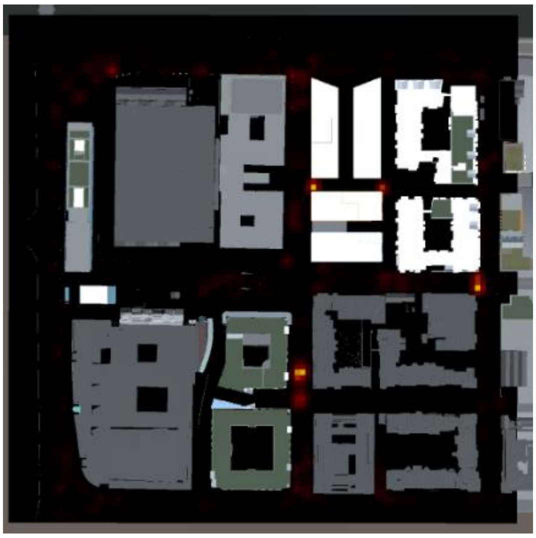


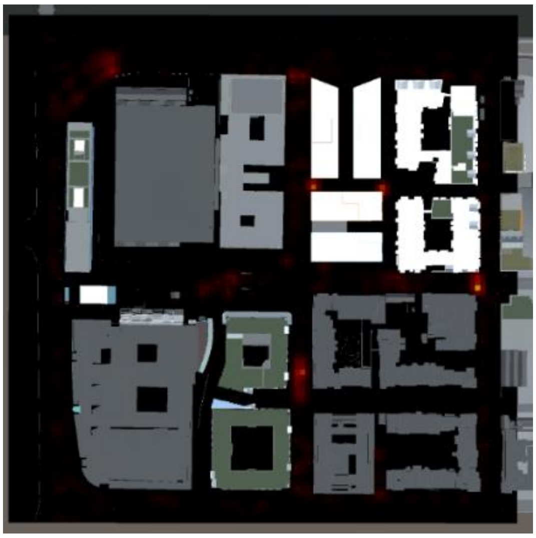
Older Agent test 2A

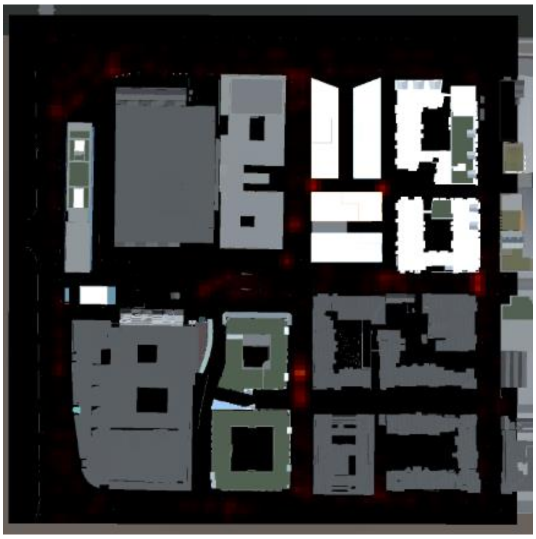
Here we can see the heatmaps of the simulations using Agents with both lower Optimism and Agility. Still apparent are hotspots in crossroads areas but the intensity has not increased as much as I might have expected given further reduced Agent Agility from test 1A. The Reduced Agent Optimism and the Agents being more conservative in the routes they chose my have an effect on these results.

Older Agent test 1B

From the heatmap we can see clear benefit from the addition of the walkability aid in the central crossroads. The concentration of falls in that area has plummeted compared to the same area in test 1A as the agents are now using the new infrastructure to more safely cross the road. Other areas in the simulation were not subject to the same improvements so we can still see the same high concentration of falls as before in 1A







Older Agent test 2B

Again, using the heatmap we can see clear benefits from the addition of the walkability aid in the central crossroads. The difference is not as dramatic as the reduction seen from 1A to 1B and I think this is both due to the less optimistic Agents more safe approach to the area in test 2A and also that some of the agents have Agility small enough that even with the improvements they could still fall

4.4 Results Discussion

From these heatmaps we can see that reducing Agent Agility has a strong association with an increase in the incidence of falls around kerbs. It was also clear that when proper path infrastructure was added the falls were greatly reduced. An interesting result from comparing tests 1A and 1B with 2A and 2B, is that even reducing the Optimism of the agents reduced the expected impact of much lower Agility on the fall rates.

Of note is that even in the able-bodied test, where all the Agents has an Agility greater than the standard kerb height, there were still falls being recorded so further investigation into the data is needed.

5 Evaluation

In the simulations described int this study, Agents could identify steps too large and these data points could be visually displayed. However, this Digital Twin City model does not seem have the detail required for accurate investigation into step heights. Anomalies exist in the model such as missing dished kerbs [22] where the slopes down to meet to road to aid Walkability, not dissimilar to my model modifications at hotspots (see below).

Figure 5.1 Digital Twin with no dished kerb

Figure 5.2 Physical Picture showing dished kerb

An unexpected result of the lack of kerb data is that my simulations were able to accurately predict the positions of these missing dished kerbs. Due to the Agent navigation properties encouraging walking on paths instead of roads, the agents optimised any road crossings to be a short as possible leading to the drawing of Agent desire lines [Desire lines][24][25] on the heatmap. With further study and tuning of the navigation properties it may be possible to use these Agent's desire lines to evaluate current pedestrian infrastructure and to inform natural positions for new infrastructure.

Figure 5.3 Real locations of dished kerbs visible from red tactile pavement

Figure 5.4 model area showing similar geometry

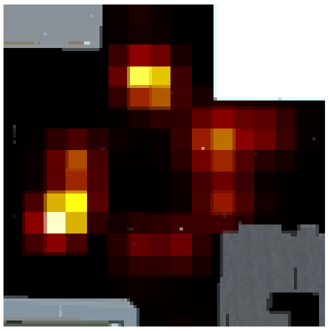


Figure 5.5 Predicted locations of road crossings

With regard to testing methodology, to maintain comparability the heatmap settings were consistent throughout the test runs. The made comparing the different tests possible however for the tests with lower fall rate this lowered the resolution heatmap results as the colour gradient is scaled such that the higher fall rate experiments still within the scales. More investigation with dynamic heatmap could provide more exploratory visualizations of each test in isolation.

To further add to this study, I would include more Agent types to investigate the Walkability concerns for more demographics. These would include wheelchair Agents which would introduce new technical challenges in detecting unsafe slopes and bumps.

6 Conclusion

This study found that Walkability concerns can be effectively evaluated using the Digital Twin City. It was also revealed that the current 3D model lacks sufficient resolution to capture all Walkability concerns, specifically with regards to step height and level change resolutions at crossings.

The study however does validify existing pedestrian infrastructure, the heat maps accurately predicting where sloped footways of dished kerbs are located. With further work this behaviour could be extrapolated to propose suitable locations for new pedestrian infrastructure, availing of Agent desire lines.

The inclusion of dished kerb details on future Digital Twin models will facilitate the performance of a more detailed future study.

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