A SPEEDY RECOVERY

Using multi-agent-based simulation for traversal optimisation in hospital environments

J. TAN,
University of New South Wales, Sydney, Australia
pugggle@gmail.com

Abstract. Inefficient floor plans could use a new approach to ensure smoother and less interrupted travel, an attribute that is especially important in a hospital setting where clashes and accidents due to poor spatial planning can have critical and even fatal consequences. Convoluted pathing and ineffective spatial planning contribute to inefficient floor plans that waste the valuable time of the staff and patients that occupy the space. Inconveniently placed points of interests such as help desks, vending machines, and windows, etc. can create obstacles. Removing these barriers can smooth out pathfinding. Pedestrian congestion is also an issue that is to be addressed as it leads to longer time to travel. To address this issue, Rhino grasshopper will be used alongside with the plug-in, Pedsim, to extract pedestrian information such as heat maps for congestion, time to reach for route efficiency and points of interest. This information will be used to form a floor plan with altered walls and rearranged points of interests that considers the different profiles groups and their traversal habits through a hospital setting. To begin with, the workflow will require a floor plan input to extract the information from. The target profile groups will be integrated by scripting unique agent groups that have their own set interests, speed, and goals, for example a patient could spawn at the stairs, have a seat, travel to a kiosk and then exit through to transit. This is one of the many narratives that will be scripted during the workflow. This will deliver an altered floor plan that will consist of optimised travel routes that will allow different profile groups to traverse in a quicker and uninterrupted manner. It will feature time-saving routes and lesser congestion. The efficiency of this will be measured by how quickly agents reach their destinations (min) as well as heat-map data that displays the absence of congestion. The proposed workflow that this research is spearheading currently addresses a hospital environment but is relevant well beyond this context to be altered for areas such as office spaces and publics areas. These alterations can be achieved through adapting points of interests and catering to different profile groups to make the applied area ideal for efficiency in time and minimalised congestion.

Keywords: *Spatial planning: multi-agent based; traversal speed optimisation; hospital environment; narrative-based*

1. Introduction: (Research context and motivations)

Inefficient floorplans can waste your precious time and congested traffic in said floorplan will just slow down your trip and make it less enjoyable. How could an 'inefficient' floorplan possibly do this? A floorplan has three main components: Its walls, its entrance/exits and its points of interests, which can range from desks, chairs windows and vending machines. Other than entrance/exits, these are essentially obstacles that stand between you and your destination. When these obstacles are placed awkwardly or with intuition without any further regard, this can impede your trip, wasting your time as you zig zag through oddly placed furniture or walking past a wall that could have been pushed back to allow the space to breathe. But there is still the question in how these wasted seconds matter at all.

Of course, seconds matter when you zoom into everyday aspects of life whether it be handing in an assignment at the cusp of midnight or getting to the stove before your steak reaches the next level of doneness. However, when provided a context such the hospital, those seconds could potentially be a lifeline for somebody. Time is a luxury in a hospital and saving it worth one's health. Time can be seen as a chronological currency, saving it essentially lets you spend it later. A doctor could use those 3 seconds to completely seal an artery before a patient bleeds out, another could save a patient's eye before they go blind.

My paper aims to provide an approach that borrows time from the trip into the operating room through simulating how one would take that trip from the office to said operating room. By simulating this we can identify that doctor's pathing behaviour and speed. This allows us to alter the walls and points of interests that pertain to that path, catering to that doctor's traversal speed.

2. Research Aims

Key aims involved focus on optimized traversal efficiency. This research aims to reduce the time to reach destination for profile groups for profile groups such as patients and the public

Reducing congestion is also a major objective as it is vital in users reaching their destination in a quicker and less interrupted manner.

3. Research Question(s)

Based on the issues outlined in the introduction and the derived aims, the question the research this project investigates is:

- How can traversal be optimised with multi-agent simulations in a hospital environment?

4. Methodology

When it comes to problem-solving, action research is a holistic approach. It is used to solve real problems in real situations which can have real change attributed to it. This action research delivers the ‘how’ and ‘why’ questions that influences practice. These questions are not always a result of statistical or quantitative procedures. “Put simply, action research is ‘learning by doing’” (Rory 1998). The quote displays the way practice can pre-emanate theory when it comes to action research. Did the chicken learn how to lay the egg or was the egg laid by instinct? Through action research, I want to think that the chicken ‘winged’ it and learnt the dos and don’ts along the way. It was aware of the goal of laying that egg but was not aware of how. The only way it can is with action research. Similarly, I had the outcomes and objectives for my research but could only make an educated guess as to how I would achieve that outcome. With action research, I was able to plan with my available knowledge, act on that knowledge, and then improve the initial plans with results of agent simulation tests and feedback by HDR. This creates a loop that goes Plan > Act > Improve upon results/feedback > Plan and so forth.

5. Background Research/Literature review

In a hospital, a matter of seconds can mean life or death, whether a doctor needed five more seconds to close an artery or three to seal a wound. What my research aims to do is to shift those seconds from the trip to the patient, into the operating room. What better way to make those seconds happen than to shorten the time needed to reach the patient. My research will explore optimising floorplans to suit traversal through agent-based modelling. The articles I will reference will explore multi-agent simulation, floor planning and optimisation.

5.1 MULTI-AGENT SIMULATION

In research by Pedro et al (2017), various methods of multi-agent simulations are explored. One method involves floor-planning that utilises real-time physics. This method has been described in a very abstract manner, as it consists of only ‘spheres’ and ‘springs’ as placeholder names for theoretical components. “The resulting bubble diagram is solved by packing the spheres using spring forces. To translate the bubbles to a floor plan diagram, the sphere is converted to squares in the three-dimensional space” (Pedro, et al. 2017). The result is semi-tangible, as the floor plan is in three dimensions, meaning that it is not completely assembled and requires user customisation to fully utilise the method. This method is intriguing in the way it can take abstract forces and transform them into customisable components I could use to optimise floor plans. However, the method lacks accessibility. It is technically complex and requires a deeper understanding of physics.

Another procedure explained was the Evolving Floor-plans method. It utilises topological and flow objectives to generate floorplans. “Chronological markers enable crossover and mutation of solutions with different topology and numbers of rooms” (Pedro, et al. 2017). This is interesting because different time periods can lead to branching out the potential of the design. I find this useful in being able to generate many variations to choose from. There is also its use of flow objectives, that minimise traffic between material usage, fire escapes, windows and classes which can very much assist in my traversal optimisation.

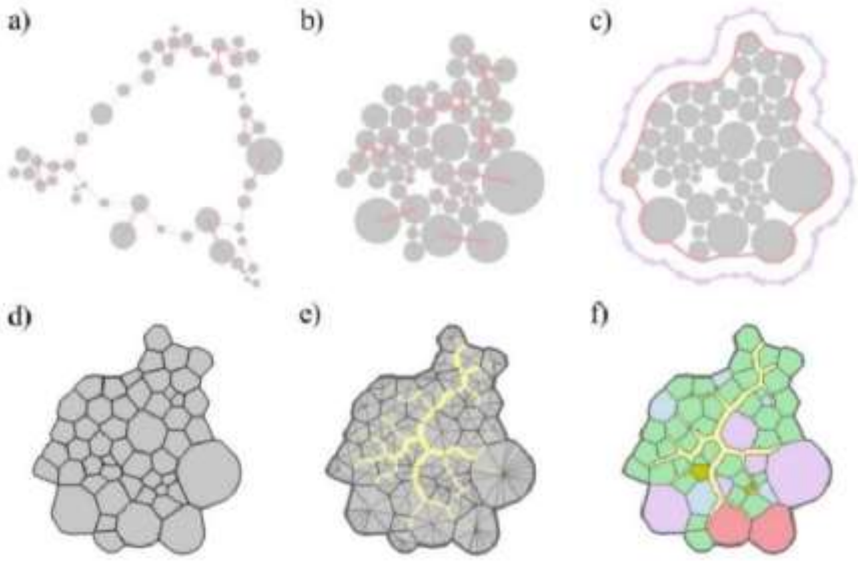


Figure 1. Pedro, et al. 2017

Fidelity is vital to agent-based modelling, as it is the axis in which its effectiveness hinges on. Michael Batty provides four different processes that dictate how an agent would behave, which include: Information gathering, Destination choice, Route choice and Local movement (Michael, et al. 2004). This involves the agent learning about the area, choosing its destination, picking a route, and then navigating its way through the area and its obstacles. The process is straight forward and easy to flesh out into an algorithmic sense, for e.g. factoring width of hallways, detecting crowded areas when choosing an optimal route.

In a hospital environment context, Davide, et al. (2019) discuss a different, more narrative driven approach. “For instance, if a patient cannot be found in his/her bed, a narrative entity can instruct a doctor and a nurse to wait, or to abort the procedure” (Davide, et al. 2019). This methodology delivers realism and diverse variations for floor plan generation regarding the many possible situations that can happen in a hospital. The only note I have is the impossibility of capturing every narrative possible within the floor plan possible. To compensate, narratives should be handpicked, based on their variety of activities that they partake in and how common their routine is. The more common it is, the bigger the amount of people that can benefit off a floor plan that puts them in consideration. A floor plan can only cater to so many narratives and with the amount of turning cogs in any floor of a hospital, there will be trade-offs.

5.2 FLOOR-PLANNING

Seongki and Ludger launched an exploration of floor planning through agent-based modelling in his 2011 paper. A main takeaway from this article was the number of trade-offs you have make, to maintain a floor plan that is not only optimised but also within the many constraints of the subject area. Seongki managed this by stating a formula which split design variables into Objective Functions, Inequality constraints, Equality constraints and Variable Bounds. Although my research is specific to hospitals, this can benefit me in managing the constraints and variables I will be working with. A noticeable flaw is the lack of pedestrian variation, an attribute that would allow for far more diverse floor plan iterations.

Another process that planned spatial areas through agent-based modelling was done by Nova A., who spear-headed a multi-agent simulation which was capable of leading to the generation of alternative space configurations. “The model based on the theory that calculates relationships of spatial requirements represented by programs through analysing their network using four analysis parameters: integration, entropy, control and choice” (Nova, et al. 2016). Their variations in pedestrian types furthered its ability to generate alternative space configurations as a result. My research would benefit from following Nova’s design parameters to map out agent modelled floor plans

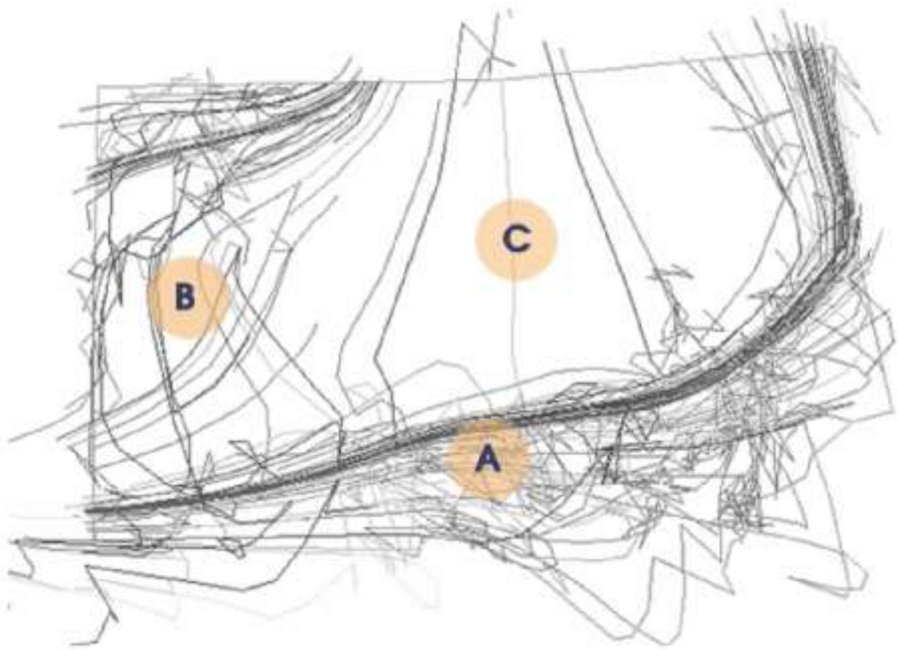


Figure 2. Nova, et al. 2016

Like Seongki, Yunqin and co delve into an approach to the simulating a crowd within a floor plan. Their method, however, has divided agent roles, which in their case included officers, judges, and the public, etc. “We need to optimise the integration value and entropy value of the plane and the path length of each pedestrian flow” (Yunqin, et al. 2019). Dividing pedestrian roles into individual path flow lengths will further increase the fidelity in which their agents move within the floorplan. Although my research will undertake a differing simulation program (Pedsim) this process will still be beneficial in defining an authentic hospital crowd flow.

These papers provide greater insight into the inner workings and thought processes that make agent-based modelling in the hospital environment as effective as it can be. Most notable are Davide’s narrative-driven approach and Batty’s four processes. These take into consideration many possible aspects and situations that deliver the vital fidelity that agent-based simulations need. There were also procedures that had insufficient beneficial areas like Pedro’s forces and springs, physics run simulation. In total I believe I have sufficient evidence of the practicality of an optimisation of floorplans to suit traversal through agent-based modelling in a hospital environment.

6. Case Study

6.1 CHOOSING A PLUGIN OR PROGRAM TO SIMULATE AGENTS

My research required a program or grasshopper program that place agents in a floor plan and have them move to and from scripted locations. It also required high fidelity when doing so, meaning agents should react authentically like people when they encounter obstacles and other people. Criteria for these included agents acknowledging other agents and not pushing them into order to complete their task. When it comes to obstacles the agents should be able to recognise that barrier and navigate around it appropriately and a regular human would.

A handful of programs and plugins were researched, they included: MassMotion, Unity, PedSim. MassMotion is an advanced pedestrian simulation and analysis software that can combine 2D and 3D assets to construct a 3D simulation. It allows you to simulate agents that travel intelligently based on user requirements. The major benefits of this software are the capabilities in simulating hundreds of thousands of agents given a few hours as well as the ability to import BIM files. MassMotion was ultimately not utilised for my research as learning an entirely new software was risky and could prove detrimental given the time frame. It was also due to my research not needing any BIM inputs or the necessity of simulating hundreds and thousands of agents for a hospital environment.

Unity was another program that was considered, as it had capabilities in simulating agents in an advanced manner. It allowed for far more customisation, with its wide variety of tools. However, learning a whole new program, especially one as large and varied with tools, was a far larger obstacle than I had time for, thus Unity was passed on.

PedSim was plugin for Grasshopper, that allowed for users to easily set up a simulation that took multiple factors such as speed and vision into consideration. The fact that PedSim was just a plugin for Grasshopper, a program I was familiar with, made it a promising approach. It also had heat-mapping capabilities as well as the timing of routes, which was essential for completing objectives. Heat mapping would cover congestion whereas the route timing would provide speed readings. These aspects combined made PedSim the ideal plugin to use for my research.

6.2 EARLY TESTING
Early testing was accomplished with a mockup floor plan with a basic version of Pedsim. This test involved a generic room with four entrances/exits and rectangular obstacles in the center. Pedsim requires points as inputs to set entrance/exit positions and so two entrances and two exits were set up accordingly.

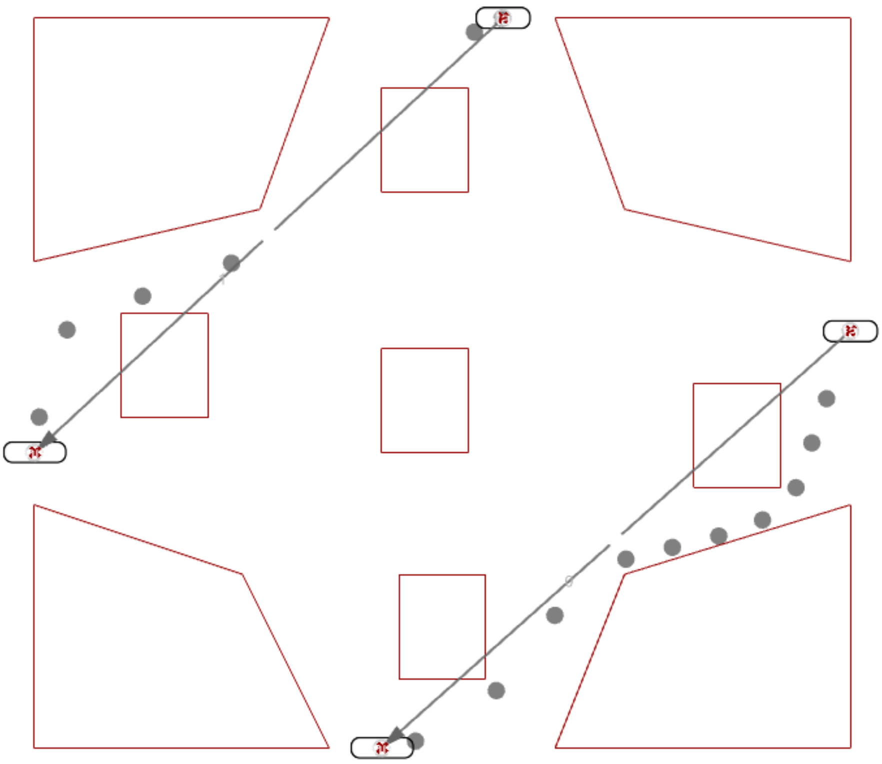


Figure 3. First agent simulation mockup

These two lines of traversal delivered a crude and linear pathing for the agents. They would bump into each other and scrape against walls to get to their destination. This was unviable as the fidelity of the agent's movements were not acceptable.

Interest points were thrown in the mix by assembling a new mockup floor plan which had L shaped help desks in the center. Agents would now stop at one of the fours points at the desks for a few seconds before moving on. This was successful in laying out a simple agent routine of Entrance > Desk >

Exit. It proved it could simulate a simple narrative of somebody entering, them checking out something at a help desk and then being on their way, out an exit. However, this was only one narrative, and my research needed to simulate multiple to authentically replicate a varied crowd.

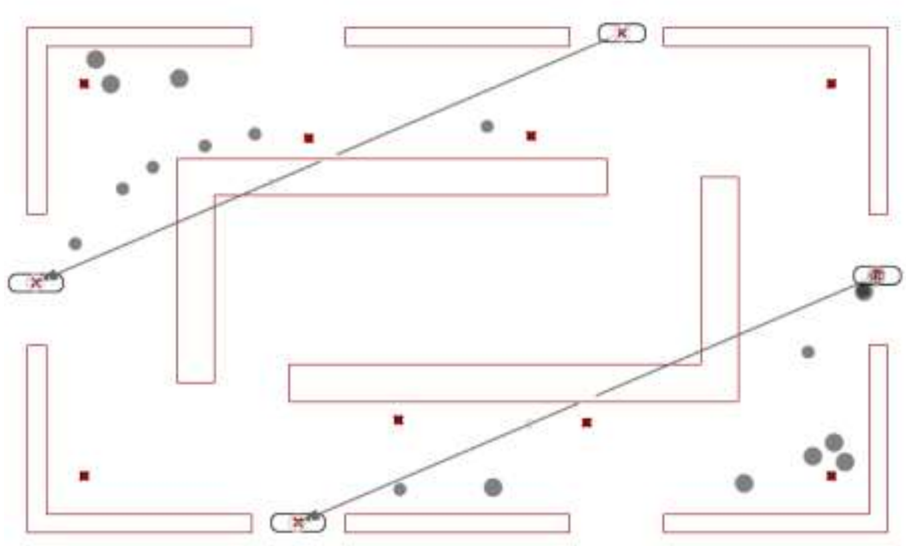


Figure 4. Simulation of two different routines

This was where other interest points were implemented, in the corners, allowing a different line of agents to respond to an alternate narrative. These agents were also given a higher speed rating so they would be in more of a hurry. This demonstrated the capabilities for the script to run multiple narratives at the same time, fulfilling the requirement for the varied routines that could roam a hospital floor.

6.3 HOSPITAL FLOOR PLAN AND PEDSIM IMPLEMENTATION

The mockup floor plans were no longer necessary, it was time for the agent to be tested in context that the paper hinges on: The hospital. HDR kindly provided a floorplan that covered multiple hospital floors in detail.

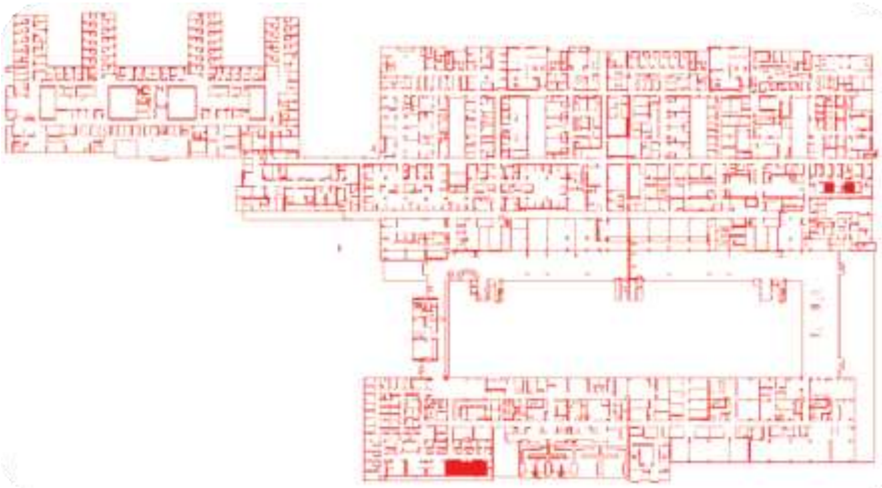


Figure 5. Hospital Ground Floorplan

The ground floor was selected, and more specifically, the public section of the floor was chosen. Since modelling a routine for the agents meant having to understand how that routine work in real life, I decided to focus on the public area, where there are less staff and more patients and visitors. Focusing on more staff-dense areas filled with profiles such as doctors and nurses requires a higher understanding of their complex routines. To allow this area to work with PedSim the boundary of the area had to converted into a closed polyline.

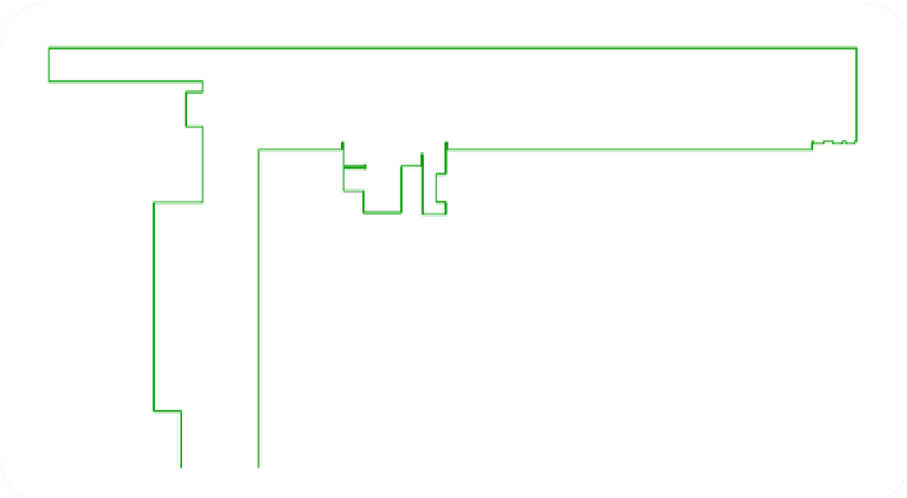


Figure 6. Closed polyline area

6.3.1 Setting up entrances/exits and points of interests

The entrances/exits that the agents were going to use were to be implemented next. Five were identified, including:

- The main entrance
- Pastoral care
- Transit
- Elevator
- Stairs

In order to have a large variety of narratives to simulate, routes between every entrance was created. The only route not included was the one between the stairs and elevators due to its impracticality.

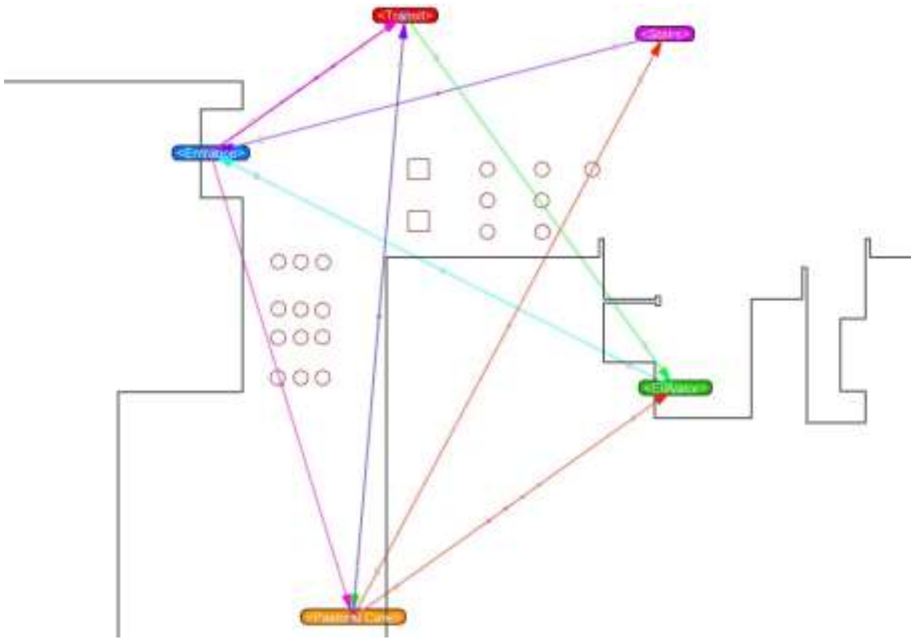


Figure 7. Scripted Routes

Information regarding entrances and exits were extracted from the initial Rhino floorplan. This included the main entrance, pastoral care, transit, elevators, and stairs. The same applied for points of interests, which included seating areas and kiosks. These points were differentiated by its time to visit, the length of time an agent would stay there. Seating areas were given a higher time to visit than kiosks.

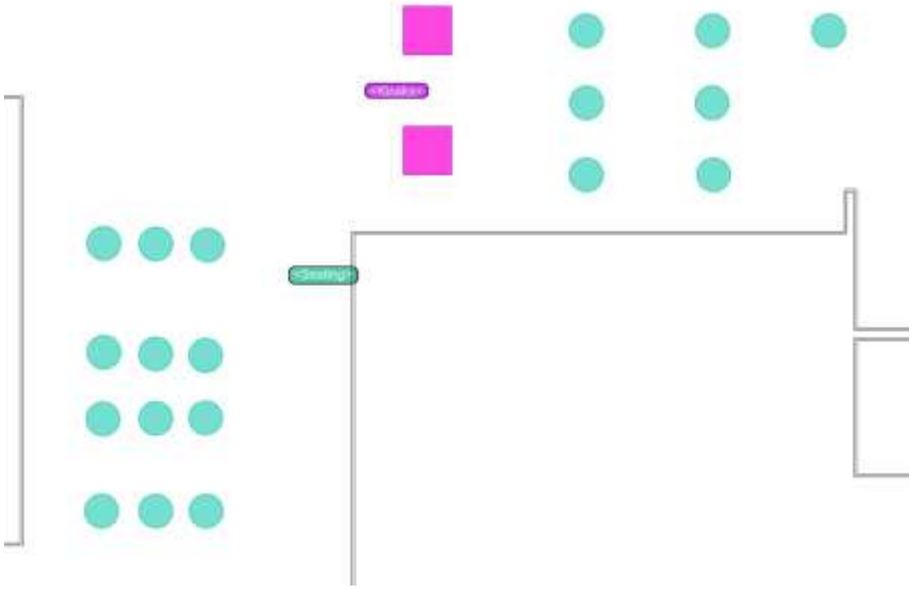


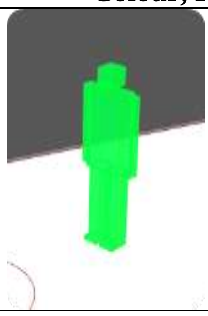
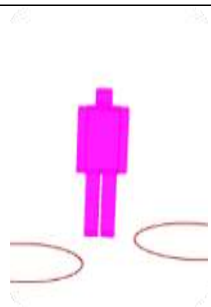
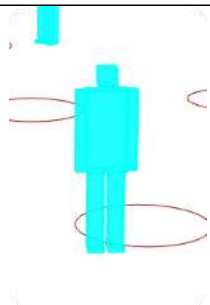
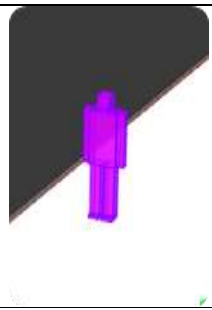
Figure 8. Points of Interests

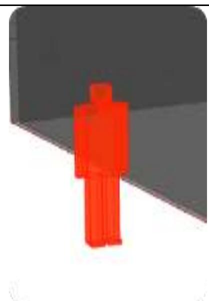
6.3.2 Creating User profiles

Creating varied user profiles was important in agent realism. Having the agents move realistically while being affected by realistic factors was a major requirement in furthering its fidelity to human behavior.

PedSim allowed multiple inputs that enabled this, including speed, angle of vision and vision distance. Speed dictated how quick an agent would traverse, agents that were perhaps in a hurry would have a higher speed. Angle of vision affected an agent’s cone of sight, somebody knowledgeable about the area would have a narrower cone of vision as they know what to expect and are travelling straight to their destinations or interests. Vision distance controlled how far an agent would see, allowing variation in the quality of eyesight that the agents possessed. Somebody with below average eyesight would have a low vision distance. Three behaviour templates were created with the above variables for profiles that suited visitors, patients, and general members of the public.

TABLE 1. User Profiles

Behaviour Template	Colour, Routes & Interests	
Speed: 5 Angle of Vision: 150 Vision Distance: 100		
	Routes: Transit > Pastoral Transit > Lift **Interests:** Seating	**Routes:** Entrance > Transit Entrance > Pastoral **Interests:** Kiosks & Seating
Speed: 2 Angle of Vision: 130 Vision Distance: 40		
	Route: Lift > Entrance **Interests:** Seating	**Routes:** Stairs > Entrance Stairs > Transit **Interests:** None

Speed: 4 Angle of Vision: 100 Vision Distance: 30	
	Routes: Pastoral > Lift Pastoral > Stairs **Interests:** Kiosks & Seating

6.3.3 Testing: Route timing and heat mapping

The initial floor plan has to be tested so that the optimised layout had results to compare with. Pedsim records each agent's start time and end time, so a script was made to subtract the averages of the end time by the start time to deliver an overall average time to reach destination. What these times were measured in was a mystery as the plugin was ambiguous in what they were measured in. The route timing provided an average of 670 units of time.

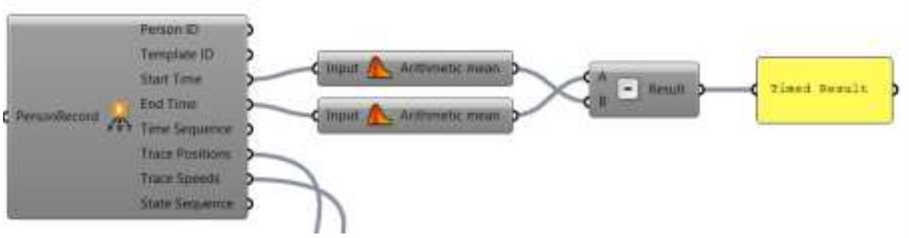


Figure 9. Average time to reach destination calculation

Heat mapping was entirely visual with no relevant numerical data to display. The hotter and higher a tile was, the more it had been stepped.

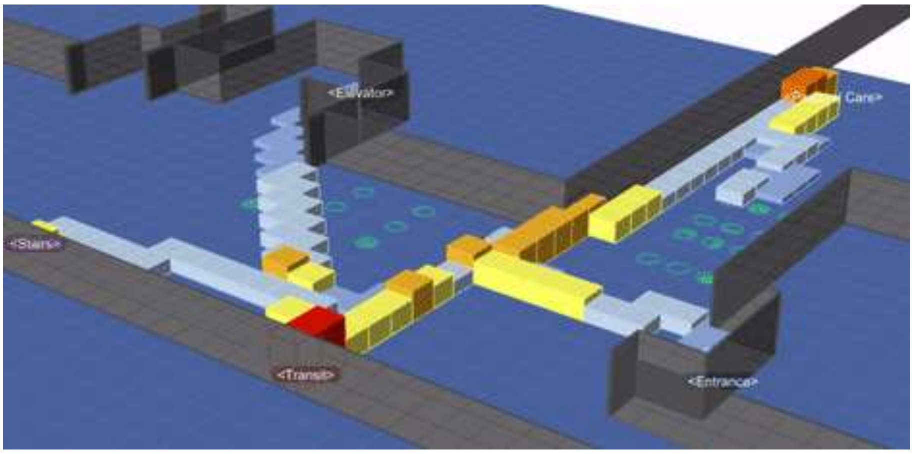


Figure 10. Heat mapping for initial floor plan

6.4 FLOORPLAN OPTIMISING

6.4.1 Wall and Interest point alteration

The floor plan was to be optimised through agent-based simulation. But how? What data could they provide to have influence over a layout alteration. It would be their pathing.

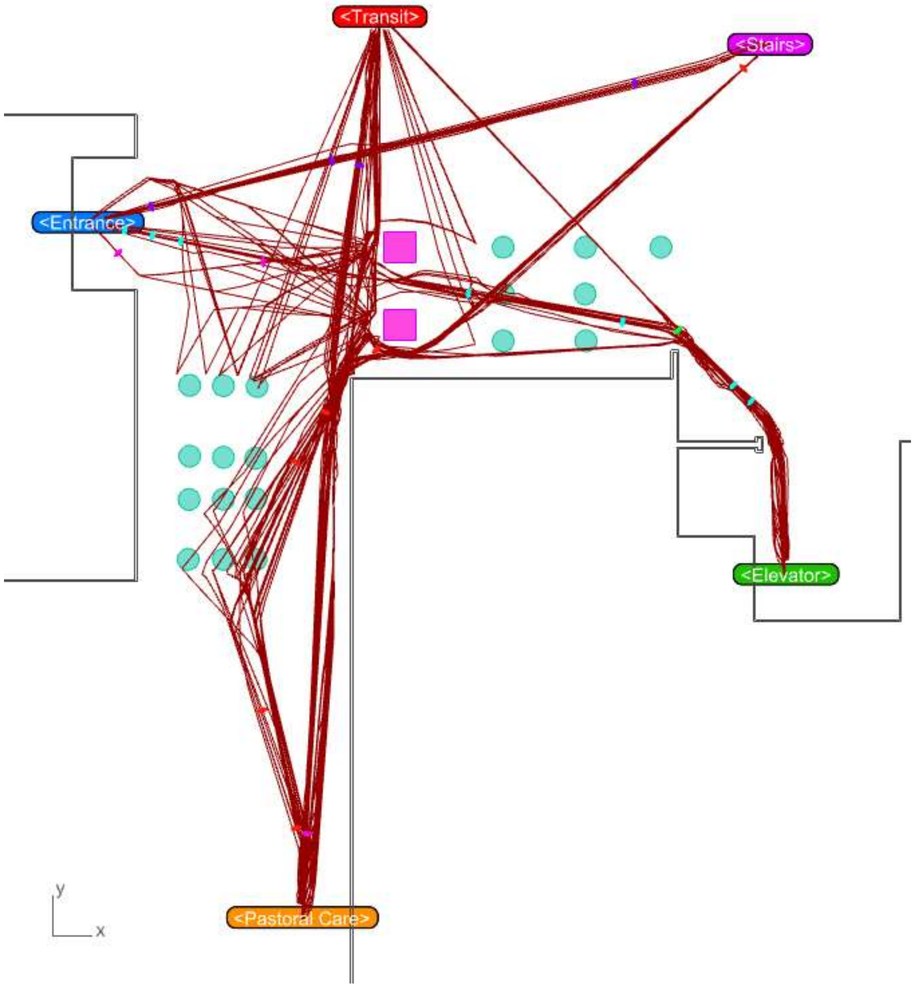
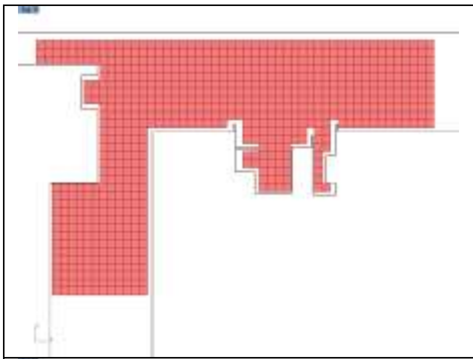
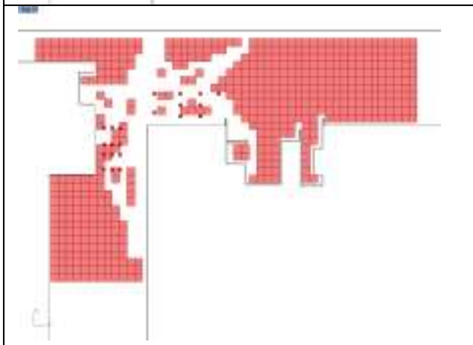
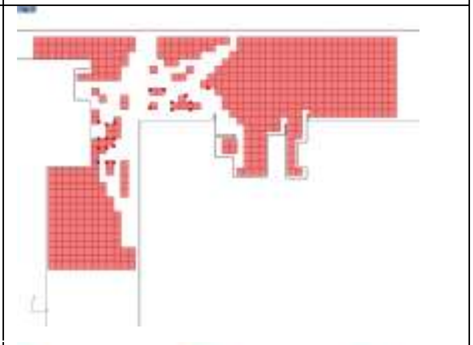
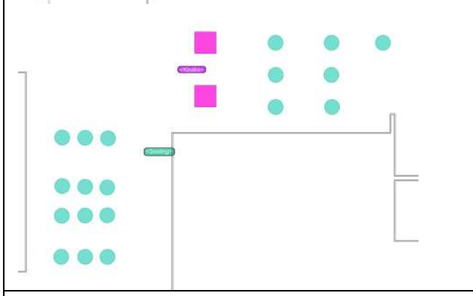
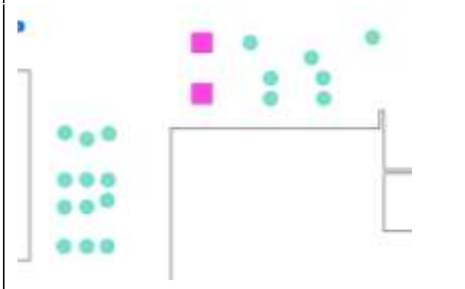


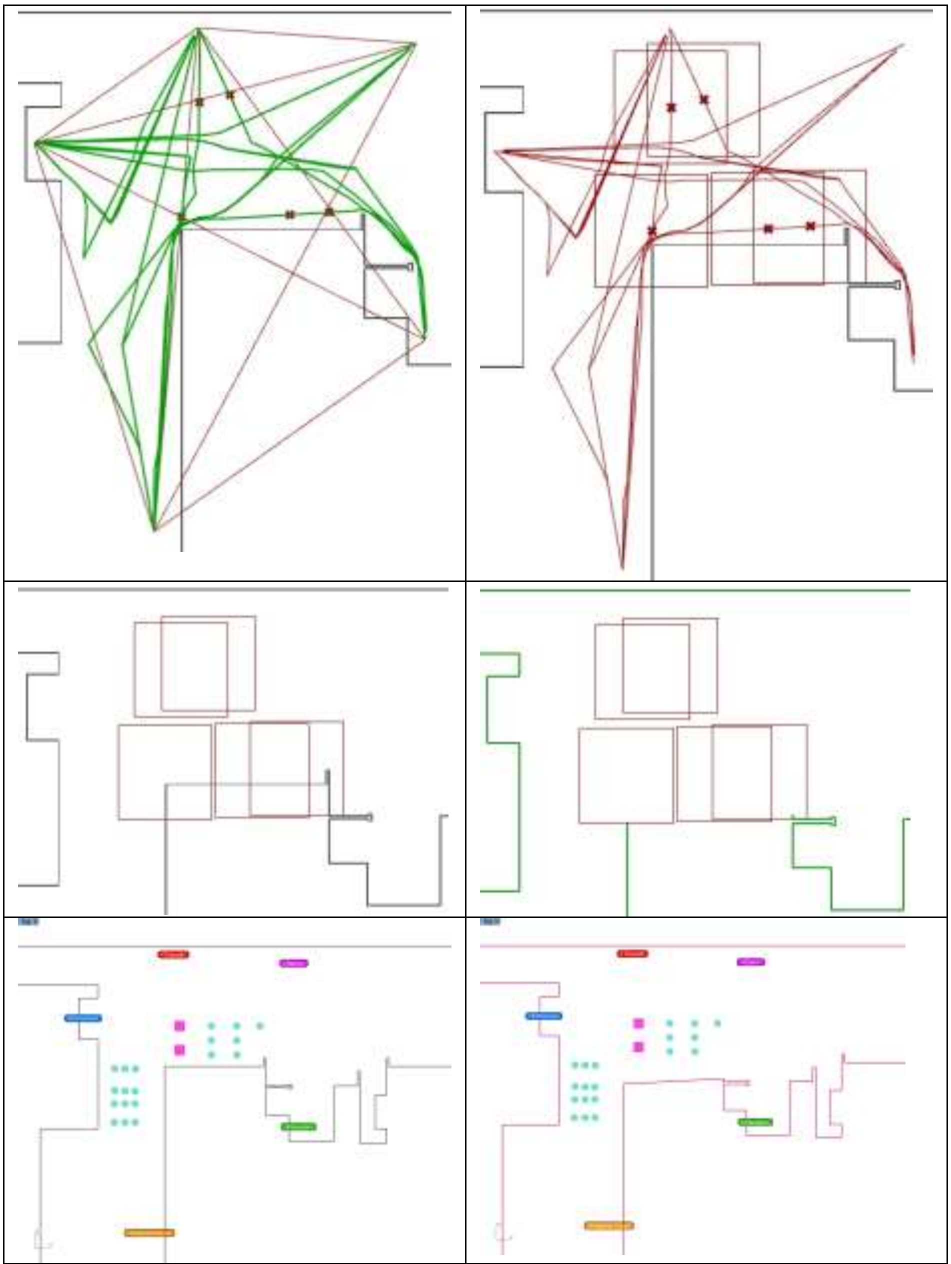
Figure 11. Agent Pathing

A grid of squares covering the floor was made and tiles that the pathing touched were culled. Points of interests were then pulled to the closest tile, meaning that they were being nudged out of the way of common agent pathing.

TABLE 2. Interest point alteration process

	
	
	
Before	After

The way the walls were altered through a combination of desire lines and pathing. Points from the intersection of desire lines were pulled to the closest path and large squares were created from those points. As the initial floor plan was chopped up into points, anything inside the squares were culled, effectively pushing back any wall that had an influence on congestion and pathing.



Before	After

6.4.2 Testing of optimised floor plan

The floor plan can only truly be called optimised once it provides proof that it is better than previous iterations. Performing the same testing process of route timing and heat mapping in 6.3.3, allowed us to find that the new layout delivered an average time to reach destination of 620, which was 50 units lower than the previous 670.

Comparing heat mapping results provided insight into how the older plan had more concentrated routes that encouraged congestion. This contrasted newer plans results as it displayed more spread out pathing, encouraging lesser congestion.

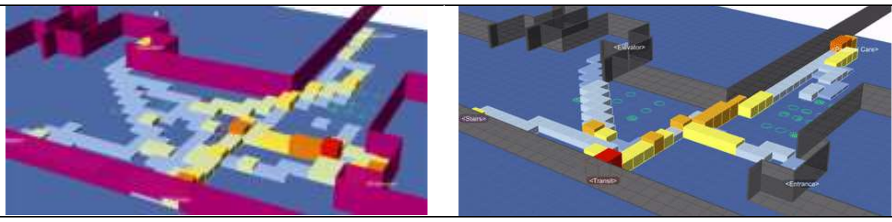


Figure 12 with Figure 10, new heat map versus old heat map

7. Discussion (evaluation and significance)

The initial aims were to increase traversal efficiency through the reduction of the time to reach destination, along with a reduced congestion. This involved reducing cutting the time that it took to reach a destination as well as lessening congestion, reducing the chance of people crowding.
This was achieved through the extraction of data such as pathing and desire lines from the agents to influence wall and interest point movement.

The criteria were for the timed and heatmapping results of the initial floorplan, to be compared to results of the altered floor plan. Through this we can see that the new floor plan provided a reduced time to reach destination as well as less concentrated pathing, shown through the heat maps.

Limitations along the way involved the 10-week time constraint. This meant only being able to work on the public section of the hospital. This is due to not knowing the complex routines that doctors and other staff undertake. Without this knowledge, the agents would not have behavior authentic to those user profiles. If there had been more time, I would have undertaken the learning process for these complex routines and applied my workflow deeper into the hospital in sections such as emergency rooms and triage.

There has been use of agents influencing the makeup of floor plans, however those projects did not provide a strong focus in traversal optimisation. The goal of increasing that efficiency in speed and minimal congestion is a field that can contribute greatly to improving the flow of the space, both in speedy traversal and comfortably uncongested areas. Further questions that could be answered and built upon is the application of this workflow to other contexts. Other contexts such as subways, office spaces and various public areas. The context could be adapted to different types of building usages.

8. Conclusion

Using multi-agent simulations, can deliver data in the form of pathing lines, heat maps and routes times, to influence a floor plan's walls and interest points. This influence can be catered to traversal optimisation, where a user will encounter less congestion and a quicker time to destination. Poorly planned out floor layouts can often have these walls and interest point be placed in a way that is detrimental to one's traversal speed. Something that is especially important to note when in a hospital environment.

Implementing PedSim has allowed a simulation of multiple agents with multiple behaviours and routines. This variation has allowed the simulation to reach a higher level of fidelity when it comes to hospital pathing. This fidelity increases the pathing's efficiency when it comes to altering walls and interest points. The floor plan as a result of altered walls and points was tested through route timing and heat mapping and compared to the initial floor plan. The shorter average times for the new plan displayed its effectiveness in saving time. The heat maps comparatively showed the initial plan possessing tighter more congested pathing, contrasted with the more spread out pathing of the newer floor plan. These are optimisations that can improve the way traversal is planned throughout a hospital environment. The seconds that this paper shaves off traversing in a hospital, could potentially one day save your life.

Acknowledgements

Thanks to UNSW and my lovely tutors:

- Hank, pretty awesome
- Nicole, the best lecturer evah
- Daniel, who has the best jokes that involve grasshoppers (ask him about it)

Thanks to HDR for the support and invaluable feedback

And most of all, thanks to my friends a.k.a dobby gang, whom I shared so many priceless moments with. This journey wouldn't have been worth it without you guys.

References

Pedro, V., Jinmo, R. & Ramesh, K. 2017. Multi-agent Space Planning. Carnegie Mellon University, Pittsburgh, USA

Seongki, L. & Ludger, H. 2011. Complex Adaptive Residential Quarter Planning using Multi-Objective Optimization. Swiss Federal Institute of Technology Zurich, Switzerland

Yunqin, L., Jiaxin, Z., & Chuanfei Y. 2019. Intelligent Multi-Objective Optimization Method for Complex Building Layout based on Pedestrian Flow Organization. School of Architecture, Southeast University

Kay, K. & Michael, B. 2004. Pedestrian Behaviour Modelling. Centre for Advanced Spatial Analysis, University College London

Nova, A. & Aswin, I. 2016. Making Sense of Agent-based Simulation. Institut Teknologi Bandung, Bandung, Indonesia

Davide S., Simon B., Rhys G., Azam K. & Yehuda E.K. 2017. Simulating use scenarios in hospitals using multi-agent narratives. Journal of Building Performance Simulation

Rory, O 1998, 'An Overview of the Methodological Approach of Action Research', http://www.web.ca/~robrien/papers/arfinal.html Accessed 29 November 2020.