USING URBAN OBSERVATIONAL DATA TO ENHANCE THE COMPLEXITY OF AGENT-BASED PEDESTRIAN SIMULATIONS

To Inform Architectural and Urban Design

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Abstract. Traditional observational methods of collecting urban data can be expensive, time consuming and labour intensive. Using agent-based simulations – entities which contains characteristics that can decide, and act based on its defined characteristics and context – we can simulate how people move through and use public spaces, which in turn can create significant shifts in how architectural and urban spaces are designed. This matters not only because it removes the need for manual on-site observations but also offers designers simulated data-driven ways to design. Utilising an iterative action research approach, the method of investigation aims to test the process of analysing observational data in a communicable manner, providing contextualised information to help inform the agent-based simulation. Real-time observational data is collected and contextualised in order to understand cultural norms to a space and mapping human behaviour. To inform and enhance the complexity of individual agents within the simulation in each iteration. The anticipated results from the simulations will show an increase in complex agent behaviour in the form of urban interactions, like that of the observational precedence. This will provide an efficient process for designers to use simulated movement data to facilitate in-depth knowledge of how it can help in urban and architectural decision making.

Keywords. Urban Data, Agent-Based Simulations, Real-Time Data, Observational Data, Behavioural Mapping

1. Introduction:

The drive towards generating optimised data-driven approaches in urban and architectural design has created a demand for simulating spaces before they're built, allowing designers to create ideal spaces for people to use.

Agent-based simulations are defined: as computational models used to simulate actions and interactions of individual 'agents' to assess the effects each agent has on the system at large (Grimm and Railsback, 2005). With the system in this case study being defined as an urban space. Additionally, each agent can contain parameters that define their actions and the likelihood of those actions occurring in the system. The benefits of simulations allow users to gain real-time feedback when designing spaces which would be built in the real world, as it allows designers to determine whether the original design had the intended effect before it's built. As a result, designers may explore the possibilities of alternative designs without physical construction (Craig, 1996). This would lead to the associated construction costs for physical changes reducing significantly as designs are studied and carefully improved within the simulation to create an optimal design solution. It's important to keep in mind with benefits of simulations, modelling accurate agents is nonetheless a monumental task and requires a precedence for which to imitate.

With the inherent complexity of agent-based simulations as a field within Computer Science, pedestrian modellers and designers have resulted in using simple mass movement programs such as Massive Software which looks at large scale movement of thousands of people, or other software such as Unity and Unreal, requiring knowledge of a programming language and the software at hand. These programs, though useful, lack either the granularity of individual agent's personas or the contain program complexities that an individual designer would lack. If designers were able to easily create accurate agent-based simulated environments of their designs, it can improve the overall workflow of optimising designs for people and create agents that can work in any similar situations.

Currently there are no accurate and easy workflows in creating agent-based pedestrian simulations without in-depth knowledge of programming and human behaviour. Thus, this research aims to demonstrate a method for creating accurate simulations based on real-time observational data.

2. Research Aims

Based on the issues found in the nature of human behaviour reflected in current pedestrian modelling simulations, this research aims to investigate ways to expand the complexity of agent-based simulations towards informing architectural and urban design decisions

3. Research Question

Based the aforementioned aims, this research project asks: *In what ways can real-time urban data be used to expand the complexity of agent-based pedestrian simulations in urban environments?*

4. Methodology

Action research is simply put, a methodology in which researchers intervene and pursue action and research outcomes simultaneously, resulting in iterations upon iterations of research, refining the process and learning from each version; or how Rory O'Brien states it's "learning by doing" (O'Brien, 1998). This methodology can be viewed as a cycle of learning (see figure 1) that seeks to continuously solve issues through "reflective and experimental inquiry" that results in conceptualising the problem, taking action and evaluating the resolution and identifying issues with the original action and resolution (MacIssac, 1996).

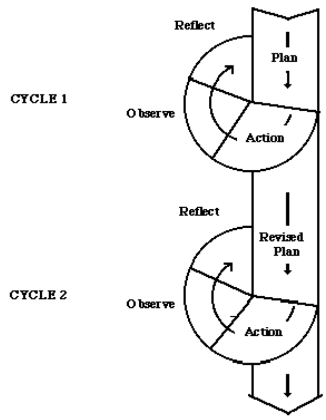

Figure 1 Stephen Kemmis' Simple Action Research Model

Action research is more than just iteration after iteration. Rather, action research is guided by principles defined out by Richard Winters: reflexive critique, dialectical critique, collaborative resource, risk, plural structure and 'theory, practice and transformation'. Each of which can be present in an action research setting. Reflexive critique is defined as "[reflecting] on issues … and assumptions upon which judgments are made" (Winters, 1989). This plays a critical role in understanding and critiquing the issue and making informed decisions, to ensure the best possible outcome in current and future iterations. Another important aspect is the 'theory, practice and transformation' principle; defining what action research truly is.

As previously stated how action research is a reiterative process of continuous learning, Winter and O'Brien defines it as theory, practice and transformation stating that "theory informs practice, practice refines theory" (O'Brien 1998). By starting with a theoretical question, action researchers are encouraged to practice their theory with any means, to help find drawbacks, which will lead to its eventual transformation to a more refined question.

5. Background Research/Literature Review

The advent of advanced computational power brought by innovations in computer processing has allowed for the rise of not just urban data provided by census and observational information but rather, a far more powerful tool that may irreversibly change the way we design, in the form of Agent-Based Simulations. Firstly, we need to understand: what is urban data and how can simulations be put to use by architects and urbanists design future spaces? Urban data (otherwise known as Big Data) are quantitative sources of information (i.e. texts, surveys, geo-spatial, meta temporal data, etc.) gathered through various digital technologies (i.e. mobile phones, cameras, meters, etc.) connected to the internet, that are either monitored in real-time or collected and analysed at a later date. These help guide urbanists to get a better understanding of current urban problems through the revelations of trends, such as how people commute to work or interact with an urban space (Joss, 2015, p. 260) Moreover, agent-based simulation – entities that contain intelligent characteristics and can decide and act based on its intelligence and other information taken from its environment – can be useful to urban analysts in the way it predicts trends around popular spaces. This allows urbanists a richer view of the ways people interact in and with space, but who they are and their certain preferences (Manovich, 2015).

William Whyte and Kevin Lynch's analysis and observations of American metropolises such as New York and Los Angeles city during the mid-late twentieth century provide a conceptual theoretical framework of the traditional method of how urban designers used to collect and analyse data – through on-site observations and recordings (Lynch, 1960, p. 14) (Whyte, 1980). When compared to the copious amounts of digital data provided by user-generated content, on-site observations seem archaic and out of place in today's modern society as the unseen digital content we produce can be as effective of a tool for urban design than observing, when in reality can provide a greater and more intimate insight than data (Schlickman, et al., 2019). In their 2019 report: The Field Guide to Life in Urban Plaza's by Schlickman et al, not only refers to Whyte's work, but also extends his findings in the digital era, where they couple on-site observations with both digital data and machine learning algorithms for heat maps; this provided the opportunity for SWA to not only reach a new level of understanding of an urban space, but validate Whyte's research by acknowledging the granularity of data provided through on-site observations, such as city 'undesirables' and other specific characteristics which would have been overlooked in the form of digital data (Schlickman, et al., 2019). Additionally, Lynch's observational studies for wayfinding behaviour has led to the development of the key conceptual features of the built environment (i.e. nodes, edges, paths, landmarks and districts) as critical elements of a city that influence how people behave in an area. Where paths may direct and landmarks attract, which in of itself would have not been recognised without traditional methods of retrieving urban data, proving its relevance in the digital age (Lynch, 1960). But what observational data has in detail, lacks in scope; both Whyte and Lynch observed cities for short periods of time throughout the year, as a result, the data gathered can be subjected to different weather, time and events, meaning that data isn't quite reliable due to the frequent inaccuracies and anomalies, as compared to current urban data, which is year round and can identify both anomalies and consistencies, creating a new layer for analysis.

Modern digital urban data presents not only a complex tool that has the ability to reshape and transform cities in resolving many 'urban diseases' such as traffic flow and housing shortages but rather as a tool to measure use, movement and behaviour of its users, allowing designers a greater insight into a space, for improved urban areas and efficient workflows (Bettencourt, 2015, pp. 12 – 13)(Pan et al., 2016, pp. 171 - 172). With current urban data, there are limitations to its use, as transparency, accessibility, privacy and, ethics must be considered when manipulating and analysing datasets; as data it of itself has become a "form of new currency" it's critical that it isn't used to benefit to those who seek to abuse it, such as retrieving private personal information, leaking or selling it, all without consent. (Eggers, et al., 2013). As a result of these issues, much of the data has to remain anonymised leaving designers lacking specific details, which may hinder the process when integrating urban data into design; but when combined with traditional on-site observations, a unique synergy occurs, allowing for the large and consistent digital data to compliment the detailed information from observations.

Moreover, in gathering urban data, it's important to grasp the concept of John Fruin's 1971 work in Pedestrian Planning and Design. Fruin introduces the concept of Pedestrian Level of Services (PLoS), a theory based on the density, speed and comfort of people in an urban context. Used as an index to help categories urban environments, with ranges from A (Lowest Density) – F (Highest Density), the model (*figure 2)* seeks help designers improve current environments through real-time data with the aim of achieving a balance between density, speed and user comfort. As a static guide to how to design urban spaces for optimising people flow and comfort, Fruin's PLoS suffers from the generalisation of each range. For different urban environments, the context is drastically different which can affect how a space is categorised under the PLoS index. Additionally, since its inception in 1971, the same index is still in use (with minor adjustments); which can be viewed as archaic, disregarding the global shift in sociocultural and economic factors such as the rise of technology and high-density living. Regardless of its outdated nature and lack of contextual understanding, Fruin's guide sets a precedence and goal for urban designers to optimise space for better use and flow.

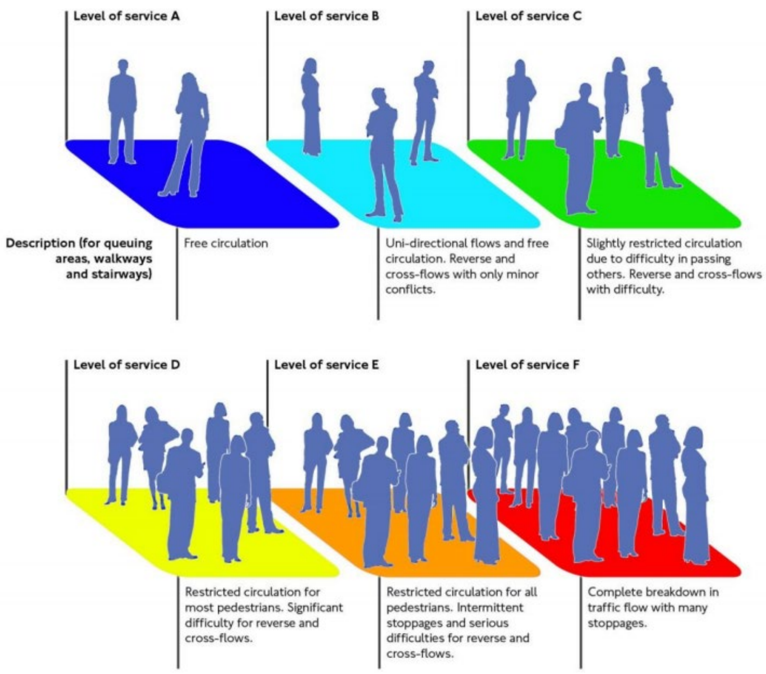

Figure 2 John Fruin's Level of Service

New research and case studies have found alternate methods, with a focus on utilising technology such as wireless tracking and machine learning for collecting and analysing urban and user-generated data within recent years. Wexin Huang's et al, 2017 research into spatial temporal behaviour exploring the complex human behaviour and environmental factors using Wi-Fi Indoor Positioning System (IPS) in Songhua, China through wireless signal strength to form a locations-based heat map (*figure 3*) displays not only the time, location and density of when people use an area, but when they're on their digital devices accessing the internet, helping designers understand when and why people use their devices in certain areas over others (Huang, et al., 2017).

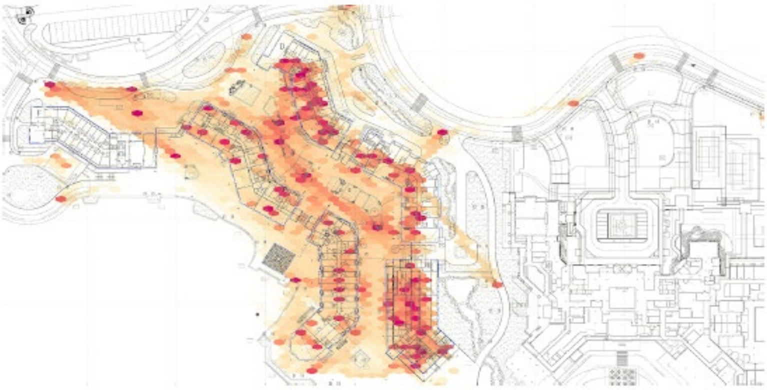

Figure 3 Wexin Huang's IPS Wi-Fi Tracking

Furthermore, the research into using machine learning in the built environment has increased. This has provided an avenue for designers to trial designs in a virtual setting; using control parameters and agent-based simulations configured for urban environments. This range of research has established on how not only users could use a space, but the flow and density. (Aschwanden, et al., 2008) (Asriana & Indraprastha, 2016) (Joyce, et al., 2010).

By enabling designers to take advantage of new alternative methods of collecting and analysing urban data, it offers the opportunity to make informed design decisions in changing and optimising the way designers approach design, in creating financial, aesthetic and personal value for the user and client.

6. Case Study

In order to gain a substantial amount of real-time data, a high-density centralized location would be needed to answer the research question; thus, the Queen Victoria Building (QVB) precinct including the Bicentennial Plaza and its surroundings was chosen as the site for this case study. Located in the heart of the Sydney Central Business District, the QVB Precinct is defined as the urban space surrounding the Statue of Queen Victoria and surrounded by Park, Druitt, York and George Streets. Not only known for its central location, the precinct has become an important landmark in the CBD due to its proximity to Town Hall station and its name sake: the Queen Victoria Building – late-nineteenth century building with a distinct architectural style. The precinct provides a small open space where users predominantly use as either a meeting spot or as a tourist attraction.

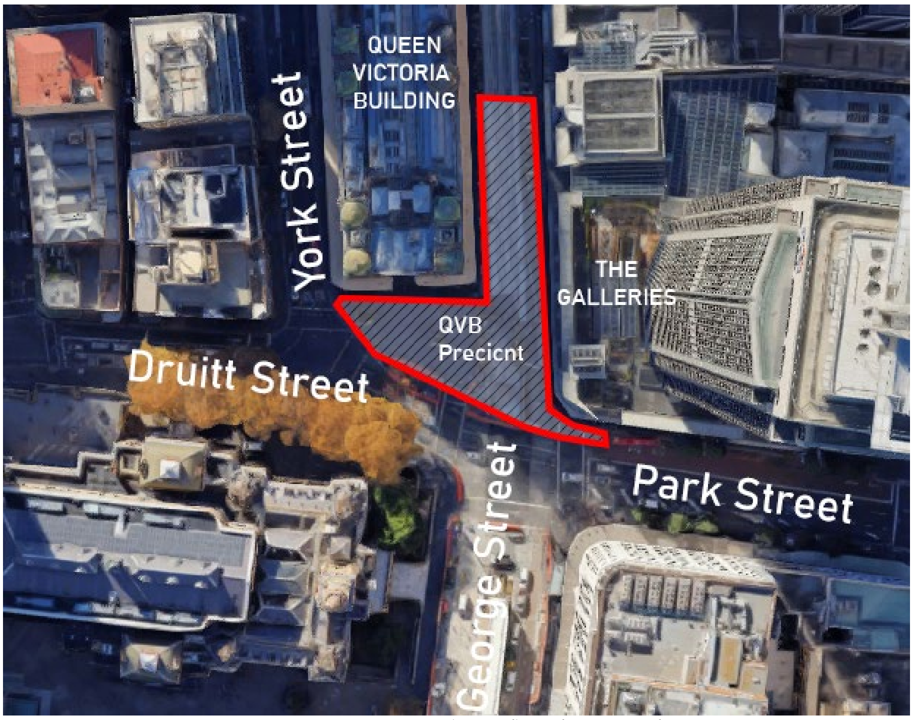

Figure 4 QVB Precinct (in Red) and Surroundings

Prior to the 2015 light-rail construction, George Street was an open road for vehicles, which restricted pedestrian movement to sidewalks; with construction further limiting the movement and attractiveness of the area. Post construction created a friendlier space for pedestrians, with far wider sidewalks, increased seating and limited vehicle access to only slow taxis and public trams. This has not only increased the aesthetic value but usability of the space. By exploring the change in this precinct, it will allow designers to not only understand what changes have been made and its effect on human behavior but most importantly, what can be made to increase the intrinsic value on the precinct.

This project is divided into three phases. Phase 1 delves into obtaining real-time data of the precinct which is then carried over to Phase 2. Phase 2 utilizes the real-time observational data to inform the simulation by identifying individual agents and key environmental aspects, iterating until the simulation and real-time data are almost identical. Phase 3 is the analysis of the simulations and its application in different scenarios.

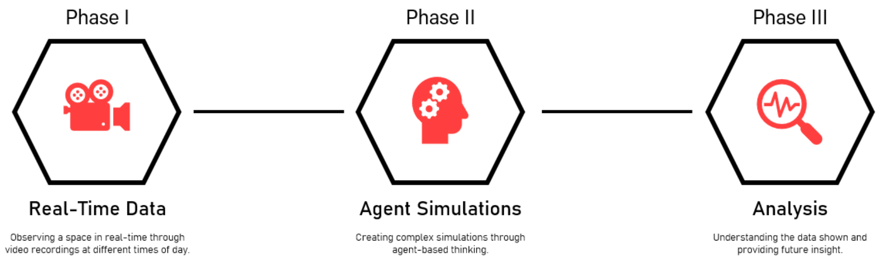

Figure 5 Graphic workflow for this project

6.1. PHASE I: OBSERVATION

Although thought of as an outdated method of movement tracking, observational data provides the most accurate form of manually gathering real-time data to date, with its ability to identify granular forms of data down to the individual. To collect to the most accurate data, a high point of view opposite the precinct was chosen as it provided a wide enough angle and perspective to observe from. Using a high-resolution camera, the QVB precinct was subjected to 10 minutes of footage broken down to 1-minute intervals at both peak and non-peak periods and at different times of day. This grants us a perspective of how the space is used by different people and the effects the contextual environment has on people's perception of space.

During the morning session at 9:30am, the space was significantly under-utilized than expected; with an estimated 40 or less people within the area. Throughout the observation, expected behaviors were showcased, from a high number of by-passers, loiters in areas with sunlight to tourist interested in the statue. Though considering the context of time and place of the recording, the area should have been relatively busy due to the 'morning rush hour'; this wasn't the case. Several assumptions can be made, the existence of a direct underground tunnel that decreases travel time and the usual arrival of work at 9am would have had a possible effect on the usage of the area.

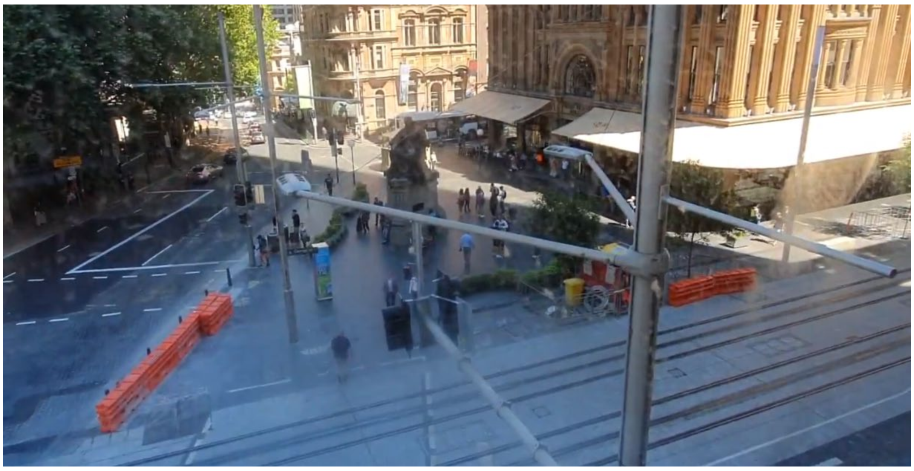

Figure 6 Morning observation of the precinct

Afternoon observations at 5:30pm provided an opposite dataset, with an increased utilization of the area, peaking at more than an estimated average of 90 people. The increased number of people in the precinct can possibly be attributed to the increase of total sunlight. A study in 2010 by the Harvard Medical School has found that sunlight has the benefit to “increase serotonin levels” and improve overall “mental well-being” (Havard Medical School, 2010). This would consciously or subconsciously attract the user to areas of exposed sunlight, inherently increasing the utilization of the space. Though behaviors for by-passers and tourists were generally the same, loitering was down by a small margin but were almost always found near the statue, which was used as a landmark.

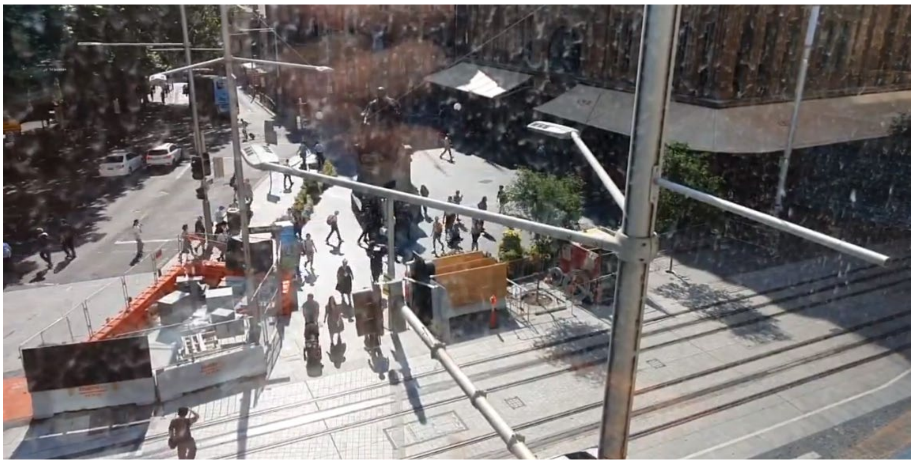

Figure 7 Afternoon observation of the precinct

As the integration of the new light-rail tracks has increased the number of street crossings, not just limiting users to the crossing from the corner of at the corner of Park and George streets; to an extent, extending the bounds of the urban space. Moreover, the open nature of the QVB precinct is subject to change, such as worksites and street entertainment which may affect how people use the area.

6.2. PHASE II: AGENT SIMULATIONS

The experimental process began with the trialling of agent-based plugins for Rhinoceros 5 and Grasshopper. Using the PedSim plugin – a simplified real-time pedestrian simulation – movement of the agents was defined by four forces. A target force that the agent is attracted to. Obstacle and Agent repulsion for avoiding immediate collisions and an Anticipation force which determines and avoids any perceived future collisions (figure 8).

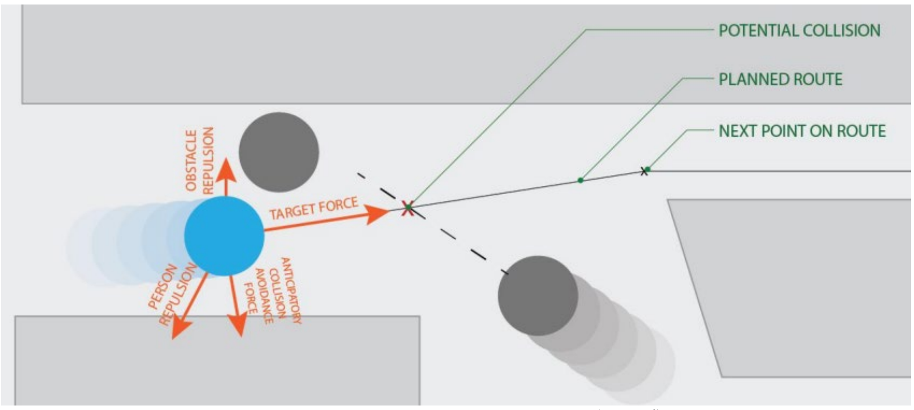

Figure 8 Forces an agent reacts to (in red)

6.2.1 TRIALING: BETA 1.5

To start, an accurate model of the QVB Precicnt had to be aquired to provide the highest quaility simulations if the form of contextual analysis. Unfortunately, with aquiring free 3D models of Sydney bearing no fruit, the decisions was made to create a simple massing of the area. Key characteristics such as roads, buildings and landmarks were modeled as poly-lines for agents to move around and geometric-points acting as an attraction; this became the base layer of the QVB Precicnt which would be itereated upon in each version.

During the initial tests, agents were given one interest before leaving the precicnt; the system showed promising visualisation of movement data through the first heat map (figure 9) showing areas of high density and movement. During this iteration, it was confirmed that the agents required extensive fine tuning to re-create human like behaviour in a virtual environment.

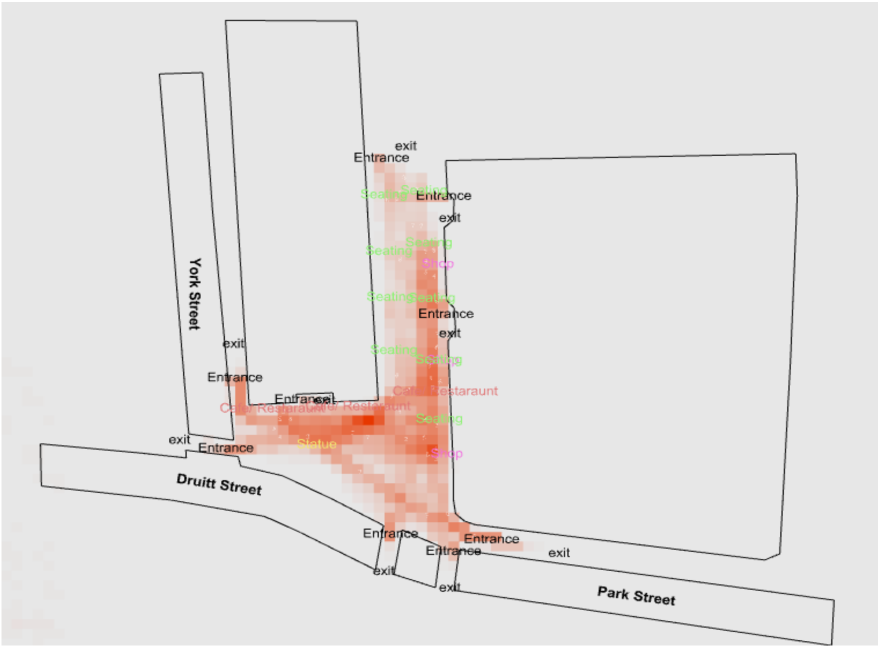

Figure 9 Beta 1.5 Heat Map

6.2.2 CREATING COMPLEXITY: BETA 2.0

With human behavior in the precinct being predictable based on previous observations, but complex at the same time with the occurrence of unforeseen variables; it's important to map agents that may help define certain characteristics and personas within the area.

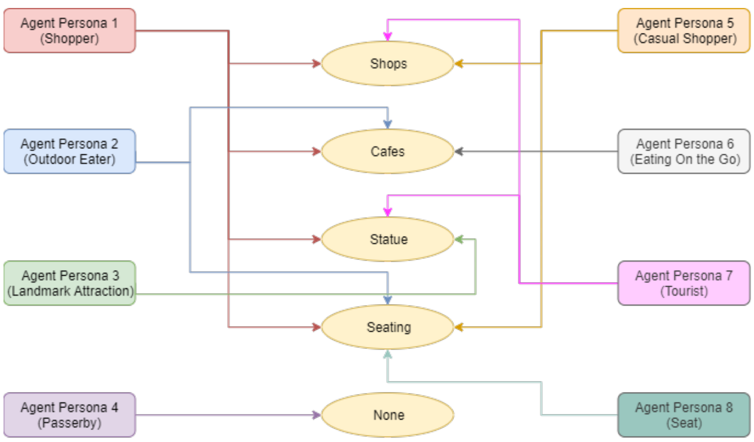

Figure 10 Beta 2.0 Agent Behavioural Mapping

Each agent was created and defined based on the common occurrence of appearing in the initial observations (figure 10). Due to the infinite amount of possibilities of how, what and when people visit a certain interest, it was decided that common personas were given multiple interests to allow for the flexibility of the agents to visit based on equal probabilities (e.g. 4 Interests = 25% of visiting 1 of the possible 4 interests). This rule however was removed for the 'Passerby' persona, which were highly likely to spawn in the space but had no interest in the surroundings, this was created to mimic those who bypass the space to reach their destination beyond the precinct.

Moreover, to increase the realism and ease in analysing the real-time observational data, the simulation was recorded at the same perspective as that of the observation, with the agents taking up a three-dimensional (3D) form. Though functionally aesthetic, the implementation of multiple moving 3D models drastically slowed Rhino and Grasshopper, to the extent that the recording had to be scaled 700% faster in post-editing in order for it to be analysed.

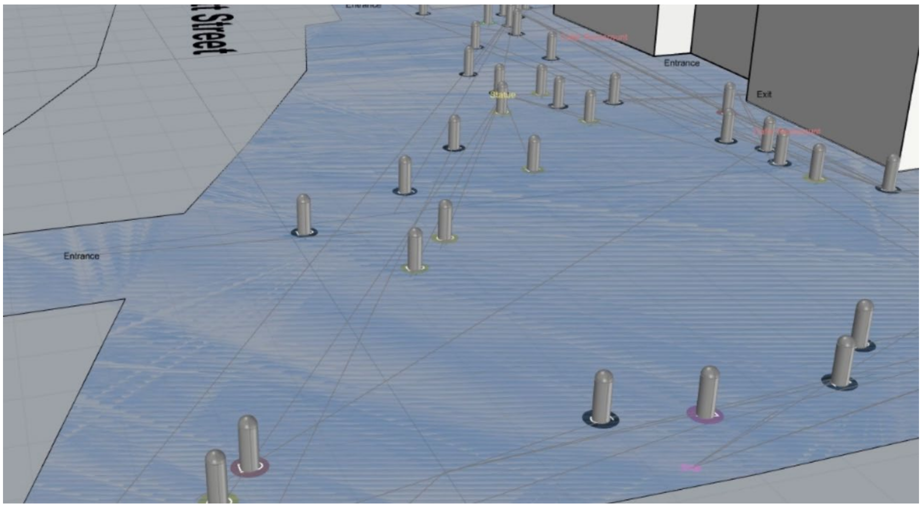

Figure 11 Beta 2.0 3D Visualisation of Simulation

The successful implementation of each of the eight agent personas has enabled a slight increase in individual complexity. With certain aspects of the Beta 2.0 simulation matching real-time data such as, idling near the statue, minimal cutting across George Street and taking a sharp turn at the corner of the QVB (figure 12). These agent behaviours show a new increase in common like human behaviours and have set a precedence for future iterations to develop upon.

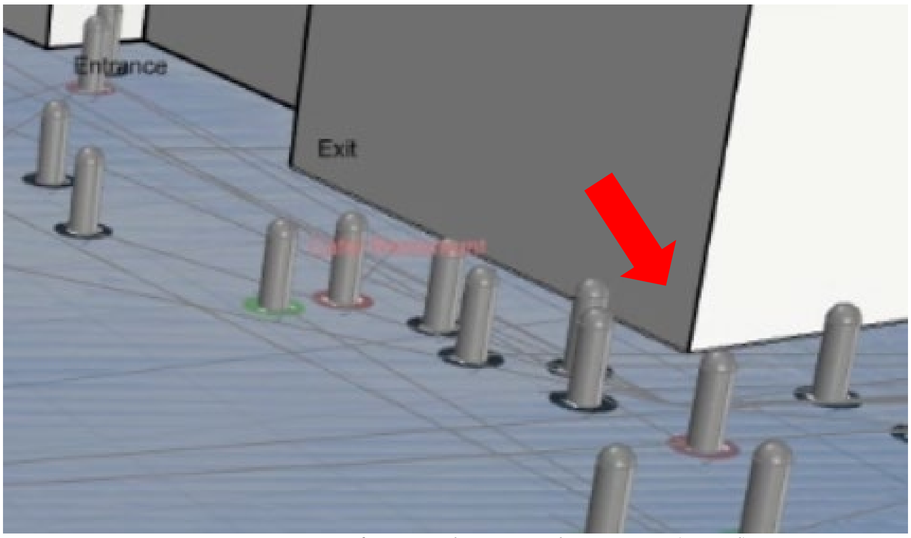

Figure 12 Corner of QVB with increased movement (in Red)

6.2.3 PEAKS AND TROUGHS: BETA 2.0.1

The next updated iteration was Beta 2.0.1; which delved into a critical aspect of high-density urban spaces: the inclusion of peak and non-peak periods. Considering the precincts location and proximity to public transport and commercial spaces, the area can be expected to have periods of high and relatively low utilization at certain times of the day.

From the initial observation, it was found that the afternoon provided a higher chance of peak usage than the morning. This coupled with the approximated amount of people in the observations has informed the simulation how many agents will be present at certain times.

With Beta 2.0.1 sharing the same agent personas as Beta 2.0, the movement was generally the same. With the only difference being the density of people within the simulation and the increased length the simulations took too complete. Both the Peak and Non-Peak simulations did however have some differences that can be considered when designing spaces. The increase of agents caused over-crowding and simulation breaking bugs in narrow spaces; these such instances should be considered red flags and thus immediately changed.

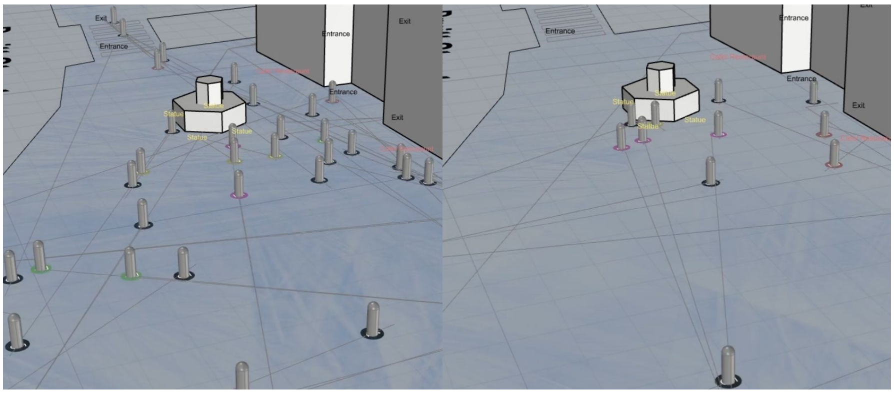

Figure 13 Peak Period (Left) Non-Peak Period (Right)

6.3. PHASE III: CONTEXT AND ANALYSIS

During this stage in the development of the prototype, previous iterations were well enough defined to display basic human behaviors found in the precinct to the point where external weather analysis plugins for Grasshopper such as Ladybug enabled another layer of information in the urban space.

6.3.1 WEATHER INTEGRATION: BETA 2.1

The integration of the Ladybug plugin – a visual weather analysis plugin for grasshopper – provided a way to visualise how not only sunlight, but wind and radiation affects the space when considering the contextual environment. In this case study, only sunlight will be used as another layer of information, as it commonly affects people's usage of space more often. Surrounded by high buildings, original observational data shows that the QVB Precinct is prominently casted in the shadow of The Galleries in the morning, with greater solar access in the afternoon. This is supported by the Ladybug model (figure 14) showing a difference in time, day and season, with greater solar access during the summer sun (greatest sunlight during the year) over the winter sun (lowest sunlight). Moreover, during the simulations, a comparison showed that like the observational data, the agents showed the ability to walk in areas of increased sunlight. However, this was entirely by coincidence as there was no current method of integrating Ladybug data as a variable for the agents.

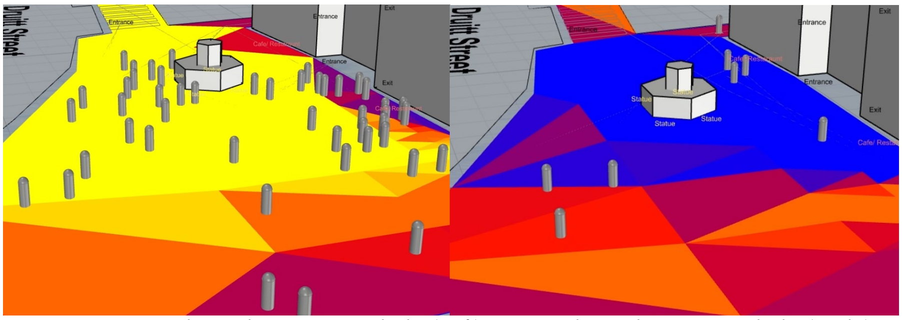

Figure 14 Peak Total Summer Sunlight (Left) Non-Peak Total Winter Sunlight (Right)

Furthermore, during this iteration, differential velocities were added to the agents, to increase the realism and comparison between the real-time and simulated data. The speed was increased by 0.5 – 2.5% as part of a ‘velocity parameter’ that allowed certain agents to increase their speed based on the importance of their task, i.e. reaching a café or their office (beyond the precinct). This was based on the premise that people tend to walk faster than others in transit areas, this resulted in scenarios where agents would overtake each other, just like in real-life.

6.3.2 FINAL PRODUCT: BETA 2.2

After four iterations – three of which used the same agent personas – it was fundamentally important to refine and increase the number and complexity of the agents and their interactions for the final product. Moreover, to test the flexibility and application of this iteration, different scenarios were created to allow designers an insight to these agents and their effects on urban design.

In Beta 2.2, a remapping of agents was required to not only visualise the levels of interests from primary (green) to tertiary (red), but the probability of certain agents spawning based on the real-time data (figure). Additionally, two interests were added based on the common but not guaranteed occurrence. Street entertainment in the form of busking or other art stalls were added, creating a small high-density area within the precinct, that fundamentally change how people use and move around the space. Secondly, certain hotspots around the statue in the observational data were identified as loitering areas; as a result, invisible points of interest were created to mimic this behavioural pattern.

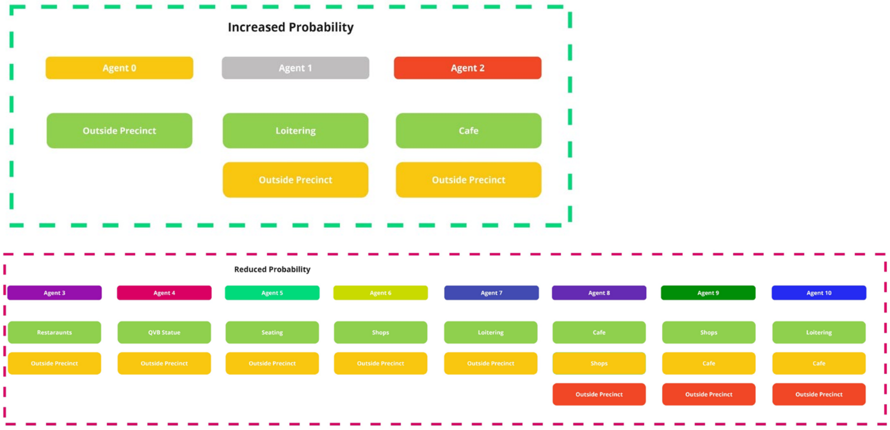

Figure 15 Beta 2.2 Agent Mapping: Increased Probability Agents (Above) Reduced Probability Agents (Below)

With the final agent mapping completed and thus implemented into the simulation, it was critical to test the practicality and flexibility of the agents. The QVB precinct was redesigned in two drastically different ways that may indicate whether behavioural and movement patterns stay the same as the space changes.

Before applying the final Beta 2.2 simulation to different scenarios, the agents were tested one final time on the current QVB precinct in order to analyse whether the final agents were able to reach the realism of the observational data. When comparing both simulations, Beta 2.2's inclusion of loitering areas as well as different areas for statue attraction created a more realistic simulation, as the real-time data showed the exact same behaviours around the statue. Additionally, movement was generally the same, with the increased probability of 'by-passers' creating the most realistic simulation of the area.

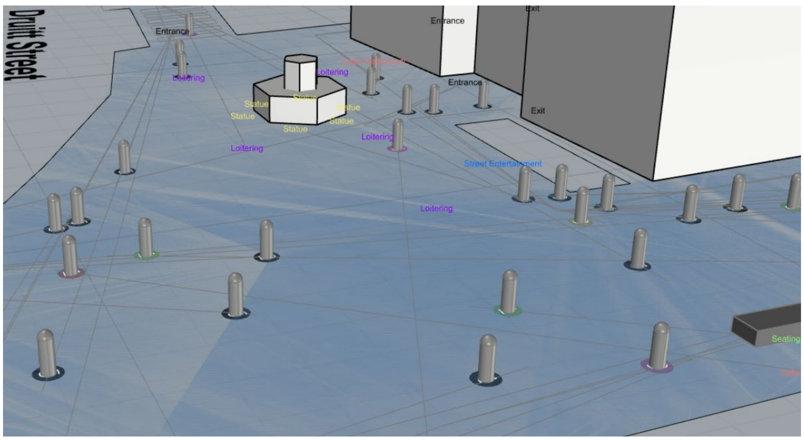

Figure 16 Beta 2.2 Simulation in the Current QVB Precinct

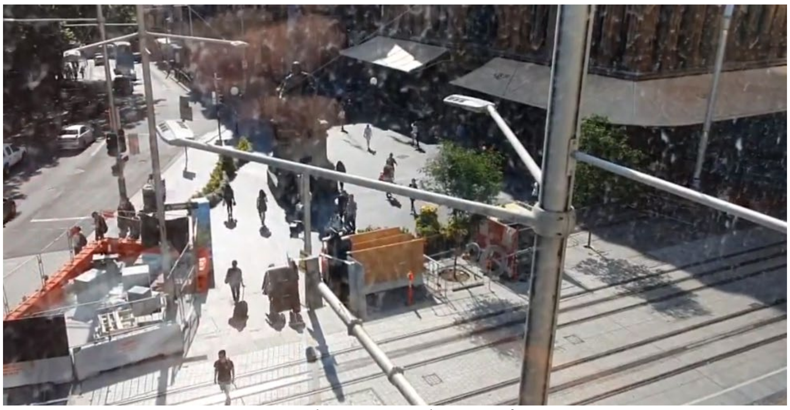

Figure 17 Observational Data of Precinct

The first scenario looks to what happens if the statue was replaced with an open area surrounded by seating (figure 16). Included in this space was street entertainment and loitering areas in the open space. This change saw the site of the old statue become far more utilised, as the agents were able to engage with the space more as seating and loitering areas attracted longer visits.

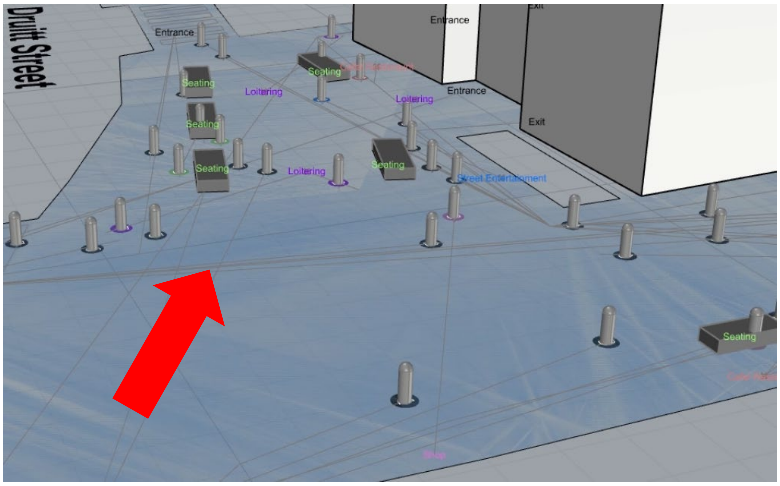

Figure 18 More Seating Scenario - Increased utilisation of the area (in Red)

Whilst the second scenario looks towards the past and reintegrates George Street as a road open to public vehicles. Though there was no easily available data regarding previous movement on the old George Street, the simulation acted as expected. With now a narrow sidewalk next to The Galleries, the level of service was high at an E or an F (figure 2), as the density in the sidewalks were crowded with agents walking by in close proximity (figure 19). This implementation, though outlandish, provides a great case study into how a redesign in a space has changed the way people move over the years.

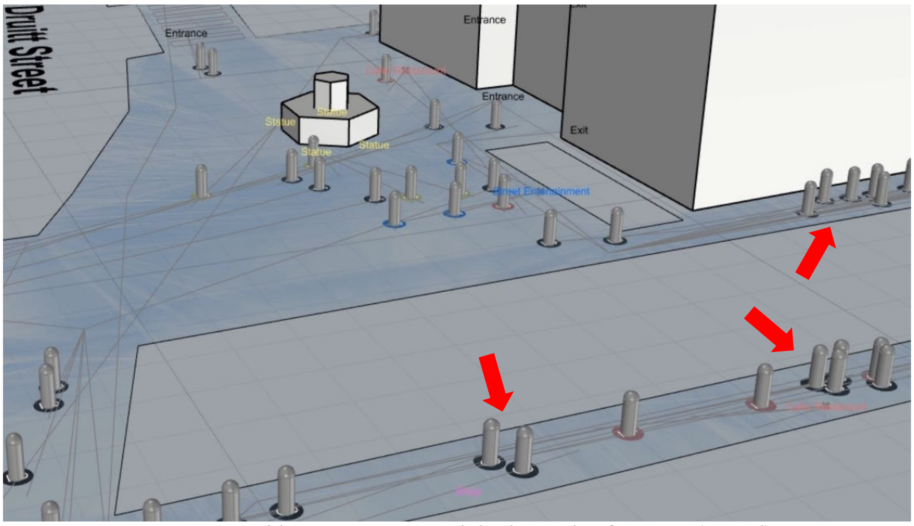

Figure 19 Old George Street with high Levels of Service (in Red)

7. Discussion

To create truly accurate human behaviors within a simulation, requires high-end thinking, whether it be knowledge in artificial intelligence or machine learning driven approches. This project has explored the benefit of utilizing the older techniques such as observational data to enhance the complexity of simple agent-based simulations to inform data-driven urban and architectural design changes.

With the goal of transforming what is widely considered the most accurate but oldest form of collecting movement data: by observing a space for hours over a period of days and weeks. The method can be viewed as archaic as it is both labour intensive and time consuming, with little integrated technological workflow. With the arrival of advanced computational processing, simulations have become a way of testing a product before implementation; this will irreversibly change the way we design, as designers can see if their projects created the indented effect on people prior to construction. This inform designers for changes to their original design, in order to gain the intended effect, the design aimed to achieve in the planning stage.

From Phase I of the project through to Phase II, the transfer of real-time observational data to a digital form in which PedSim could understand was successful to an extent. Unfortunately, accurate transferring of movement data wasn't possible under the limitations of Rhino, Grasshopper and PedSim; a work-around was the manual identification and input of characteristics into the simulation through observing the real-time data. This, though labour intensive, provided a successful complex simulation, within an order of magnitude; this more importantly has set a precedence for future simulations to build upon through updates to the agent's personas or simulating different environments. This will provide useful in the field urban and architectural design, with the current emphasis on urban regeneration and 'designing for people' that firms within the Architecture, Engineering and Construction (AEC) industry are striving towards.

Phase III further showed the limitations of the software used. Though Ladybug proves to be a useful tool for weather analysis and as a layer for informing design, its non-compatibility in influencing simulation movement is critical; as stated before, increase sunlight improves a person's overall wellbeing, affecting how people comprehend an urban space. Other limitations which would have increased the realism of the simulation such as creating groups of agents to mimic families or couples, implementing Fruin's level of service for personal space and improving the agent's overall intelligence would benefit the system and provided a greater insight into a virtual urban space.

As this project provides a framework for future agent-based simulations, further study into using other methods such as telecommunication data and machine learning will prove valuable for designers looking to automate and optimize traditional methods. Telecommunication data provided by mobile phone carries, though lacking in granularity, provides to gather a far accurate and broader range of data, from their origin and destination to their gender, moreover it provides an instant source of readily available data, at a significant price. Machine learning algorithms provide an automated alterative to real-time observational data, through Object Detection and Tracking (ODaT). Ignoring the ethics behind it, companies such as Amazon Web Services (AWS) DeepLens and algorithms like DeepSORT detect and track people within the camera's vision. If integrated, would automate the manual process of identifying activities and counting the number of patrons, enhancing the workflow of the project substantially.

8. Conclusion

This project has used observational data to feed into the complexity of agent-based simulations. This has explored the possibilities for recreating accurate human-like behaviour in simulations for predicting use in urban spaces. Due to the inherent limitations of Rhino and Grasshopper as a mainly static Computer-Aided Design program; dynamic moving simulations of multiple agents can drastically slow the simulation thus limiting the total amount of agents visualised, reducing the overall realism. Additionally, the system thus far doesn't allow for groupings of families and friends, which was a common occurrence in the QVB precinct. In the case study, gathering observational data, though quite time consuming, provided a precedence for the simulation in enhancing the complexity of the individual agents. This was done by analysing human behaviours in the space and comparing it to the base simulation. By comparing each agent within the simulation was given new behaviours in every iteration in order to achieve life-like human simulations. This allows for the use and future growth of agent simulations, making the pedestrian modelling more efficient and effective. Moreover, the flexibility of CAD programs allows for agents to react different situations in multiple contextual settings outlined by the designers, allowing an analyses on the impact of future circumstances. With simulation reaching a high level of realism to a degree, these agents flexible enough be applied to any scenario a designer wishes to analyse and explore. Not only helping optimise and automate urban and architectural design workflows but to create better and inclusive spaces for everyone to enjoy.

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References

Aschwanden, G., Halatsch, J. & Schmitt, G., 2008. Crowd Simulation for Urban Planning, Zürich: eCAADe & ETH Zurich.

Asriana, N. & Indraprastha, A., 2016. Making Sense of Agent Based Simulation, Bandung: Institut Teknologi Bandung.

Craig, D., 1996. Advantages of Simulation. [Online] Available at: <http://web.cs.mun.ca/~donald/msc/node6.html> [Accessed 29 November 2019].

Eggers, W., Hamil, R. & Ali, A., 2013. Data as the New Currency, London: Deloitte.

Fruin, J., 1971. Designing for Pedestrians: A Level-of-Service Concept. New Yrok: s.n.

Grimm, V. & Railsback, S., 2005. Indidivudal-based Modeling and Ecology. New Jersey: Princeton Press.

Huang, W., Lin, Y. & Wu, M., 2017. Spatial-Temporal behaviour analysis using big data acquired by wifi indoor positioning system, Tsinghua University, University fo Chinese Academy of Sciences , China, Hong Kong: CAADRIA.

Joss, S., 2015. Data City. In: Sustainable Cities. London: Palgrave, p. 252.

Joyce, S., Tabak, V., Sharma, S. & Williams, C., 2010. Applied Multi-Scale Design and Optimization for People Flow, Bath: University of Bath - UK.

Lynch, K., 1960. Image of a City. Cambridge: MIT Press.

O'Brien, R., 1998. An Overview of the Methodological Approach of Action Research. [Online] Available at: http://www.web.ca/~robrien/papers/arfinal.html#_Toc26184651 [Accessed 18 10 2019].

Schlickman, E., 2019. Field Guide to Life in Urban Plazas, New York: SWA.

Schlickman, E., Domlesky, A. & SWA, 2019. Field Guide to Life in Urban Plazas, New York City: swa.

Whyte, W., 1980. The social life of small urban spaces. New York: Ingram.

Winters, R., 1989. Learning From Experience: Principles and Practice in Action-Research, Philidelphia: Falmer Press.