Developing an Adaptive Building Evacuation Simulation and Decision Support Framework using Cognitive Agent-Based Modelling

Therese Anne Rollan
Swinburne University of Technology
trollan@swin.edu.au

Leorey Marquez
CSIRO Data61
leorey.marquez@data61.csiro.au

Caslon Chua
Swinburne University of Technology
cchua@swin.edu.au

Abstract

Preparing for an unprecedented event involving the movement of populations could take up large amounts of resources if done conventionally. The main motivation of this study is the behavioural modification approach which is an underexplored potential in evacuation dynamics, offering new possibilities in terms of practicality and ease of implementation. This paper tackles an adaptive building evacuation simulation and decision support framework that will serve as a guide to evaluate and propose evacuation strategies for disaster management researchers and decision-making authorities. The framework mainly involves the formulation of the cognitive agent model, the evacuation simulation, and the decision support. The timeliness in the Philippine context of the long-overdue "Big One" earthquake, the vulnerability of the case study, and the capability of the framework to be a standard guide where components can be customized by users based on the disaster type and site-specific requirements make this research a significant undertaking.

1. Introduction

Preparing for an unprecedented event involving the movement of populations could take up a large number of resources if done conventionally without taking advantage of ever-progressing technology. Preparedness, as one of the stages of disaster risk management [1], involves the planning of evacuations and the conduct of evacuation drills. Chu and Law [2] showed that up to 40% efficiency upturn on the egress time can be achieved if the evacuees have ample familiarity with the distribution of paths and exits. In this respect, evacuation drills would significantly increase familiarity with the evacuation routes and procedures that will be used once an actual disaster happens.

A system involving an evacuation simulation with a decision support tool has the capability to propose and evaluate the efficiency of an evacuation plan. In designing such system, the challenge is on accounting for human performance with respect to an individual's emotional state and level of familiarity with the place's signages, routes and exits [3], and other cognitive-related factors that may affect the evacuation efficiency.

In this study, the main goal is to develop an adaptive building evacuation simulation and decision support framework that will serve as a guide to evaluate and propose evacuation strategies for disaster management researchers and other technical groups who are working with stakeholders who possess the decision-making authority. The timeliness of the research in the Philippine context of the long-overdue "Big One" earthquake, the vulnerability of the case study, and the capability of the framework to be a standard guide where components can be customized by users based on the disaster type and site-specific requirements such as evacuation protocols make this research a significant undertaking.

Marzouk and Mohamed [4] developed an integrated building evacuation simulation with multi-criteria decision-making. However, their focus is on the integrated system and suggested the incorporation of detailed human behaviour to produce a more realistic approach. To address the challenge of accounting for human cognitive-related factors that may affect the evacuation efficiency, the main motivation of this study is the Behavioural Modification Approach which is an underexplored potential that possesses a major knowledge gap in evacuation dynamics [5]. This approach offers new possibilities in evacuation management in terms of practicality and ease of implementation that are not available in architectural and path/schedule planning solutions [5]. With this approach, people are viewed as the solution and not a burden that can cause chaos. To demonstrate and incorporate this approach to the framework, an online earthquake behavioural survey was designed based on various disaster-related population profiling and conducted to the population of the case study. The survey contains items on demographic information, past experiences on earthquake and evacuation drills,

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personality including survival-related traits, emotions and behavioural decision-making. There are existing models such as Belief-Desire-Intention that can be used to model the agents. However, these existing models do not consider the previously mentioned factors that this study would like to explore. Hence, the survey responses were processed using cluster analysis and structural equation modelling. Applying Agent-Based Modelling (ABMS), the corresponding results were the foundations of the cognitive agent model. ABM provides agents with decision-making abilities based on their distinct attributes and goals [6]. Another important consideration is the complexity brought by multi-storey buildings such as the case study in this paper with 9 floors, each of which has varying use (e.g. canteen and offices on the 2nd floor, classrooms on the 4th to 6th floors, court and activity area on the 8th and 9th floors). Multi-storey structures add layers of complexity to evacuations due to the fact that more floors entail more evacuees and require more complex exit strategies. As more lands are being urbanized and urban areas are being built with more tall structures, the evacuation of these tall structures is of increasing concern. This is supported by researchers [7, 8, 9] as they encourage existing and future studies to provide more attention to complex structures such as multi-storey buildings. To effectively visualise the 9-storey building, produce a continuous 3-dimensional space and simulate with relative ease, Unity game development software was employed in the evacuation simulation component of the framework.

With the abovementioned, the contributions of this study are as follows:

i. A detailed representation of agents representing the university population that takes into account past disaster experiences, personality, emotion and behavioural decision-making. Agent attributes are assigned based on the results of a profiling survey conducted with the actual occupants of the study site,
ii. Implementation of the behavioural modification approach as the foundation for efficient evacuation. This approach will be used to review and improve safety protocols and practices,
iii. Application of the evacuation simulation on a multi-storey building in a 3D environment, and
iv. Provision of a decision support tool that will evaluate existing and propose new evacuation plans and strategies, adapting to the dynamics of agents' evacuation performance.

It is important to note that while the case study used to demonstrate the evacuation framework involves earthquake as the subject disaster, the framework is designed to be adaptable to other types of disaster in need of building evacuation. In implementing the framework for other disaster types such as fire and flood, corresponding models and evacuation protocols must be incorporated in the proposed building evacuation simulation and decision support framework.

This paper is organized as follows. Section 2 introduces the problem through background on the long-overdue "Big One" earthquake in one of the main fault lines in the Philippines and how vulnerable to earthquake the chosen case study site is. The literature review for cognitive aspects affecting evacuation performance and factors that can be considered for the decision support is discussed in Section 3. Section 4 describes the preliminary work on this study including the adaptive building evacuation simulation and decision support framework and the cognitive agent attributes and activity diagram. Lastly, Section 5 presents the conclusions and future work of this study.

2. Problem Description and Case Study Rationale

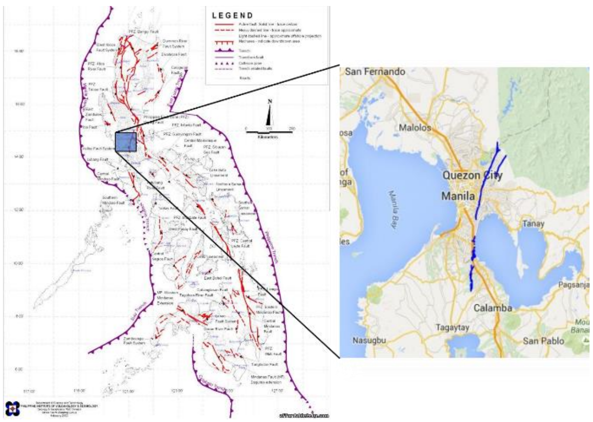
2.1. Expecting the "Big One"

The subject of the case study is a metropolitan university in the Philippines which is planning for the occurrence of the "Big One" earthquake. The Philippines is situated in the Pacific Ring of Fire which accounts for 90% of the world's earthquakes [10]. Because of its location, the Philippines frequently experiences ground shakings ranging in magnitude from those unperceived by humans to very destructive ones such as the recent 7.2-magnitude earthquake in Davao [11] and the magnitude 7.9 Moro Gulf earthquake [56], the strongest earthquake on record.

Metropolitan Manila, the Philippines' most highly urbanized region that includes the capital city Manila and 15 other cities, stretches onto a major fault line called the West Valley Fault System which according to the Department of Science and Technology - Philippine Institute of Volcanology and Seismology (DOST-PHIVOLCS), is overdue for no less than a 7.2-magnitude earthquake called the "Big One" [12]. Earthquakes in this fault system have a recurrence interval of 400 to 500 years, and since the fault system has not triggered a major earthquake since 1658, the occurrence of the "Big One" is expected in the relatively near future.

To promote awareness and preparedness, DOST-PHIVOLCS published the Philippine Fault System Map (Figure 1a) online to make it more accessible to the public. The map shows the West Valley Fault System (Figure 1b), stretching up to 130 kilometres and covering Metro Manila and 13 Luzon provinces. DOST-

PHIVOLCS also publishes the National Earthquake Monitoring and Information website to provide timely information on significant earthquakes and tsunamis [13], and distribute documents containing guidelines for actions prior to, during and after earthquakes. PHIVOLCS warns that the “Big One” earthquake can strike at any time due to recent observed irregular movements along the West Valley Fault. These observations have underscored the urgency of completing the disaster planning and emergency response training of government agencies.



(a) (b)

Figure 1. (a) Map of the Philippine valley fault system, (b) The West Valley Fault [14]

2.2. Vulnerability of the Study Site

The National University (NU) Manila campus will be the focus of the evacuation simulation case study. What sets apart this setting from other places is its large population density and lack of large surrounding open spaces for evacuees and emergency responders as seen in Figure 2.

The university holds a student population of around 8000 in its main campus in Sampaloc, Manila around 8.4 km from the West Valley Fault. HazardHunterPH [15], an interactive online hazard map website powered by the Philippine Institute of Volcanology and Seismology, identified the campus as prone to ground shaking up to intensity 8, with high potential for liquefaction. Because of its proximity to the West Valley Fault, the complexity and width of street network, and the unavailability of large open spaces for evacuation, the NU-Manila campus currently presents the risk of producing a high number of casualties in the event of the “Big One” earthquake. There is a crucial need to assess the campus’ earthquake response and evacuation plan under different disaster scenarios and conditions in order to identify the components that will bring about the most effective evacuation strategies, supply the most critical resources and minimize the number of casualties.

Figure 2. National University Manila Main Building (above) and the vicinity [16] of the campus (below delineated in yellow)

3. Evacuation Simulation Studies

3.1. Demonstrating Cognitive Aspects affecting Evacuation Performance

In developing an emotion-based evacuation simulation framework, Mao *et al.* [17] identified some of the challenges to enhance realistic simulation results of crowd evacuation namely 1) portraying the influence of emotions in the evacuation process under different conditions, and 2) the role of third-party authorities (e.g. policemen) in managing the emotion of the crowd and guiding the evacuation. Bourgais *et al.* [18] demonstrated a detailed process of applying cognitive architectures and social relations wherein they were able to integrate twenty emotions divided into three groups namely emotions related to events, emotions linked to other agents and emotions linked to actions performed by agents. Liu *et al.* [19] developed an emotion model with three factors namely individual emotion, perilous field emotion, and crowd emotion illustrating the dynamic process of an individual in a group. Regardless of the individuals’ personality (whether positive or negative), Xue *et al.* [20] found that the presence of situation-based conditions such as long waiting time and high degree of urgency produce negative emotions that can induce confusion in a crowd queueing to exit. Other factors can affect emotional contagion in a queuing scenario, namely the initial state, the personality parameters, the number of administrators and fences, the timing of the occurrence, and the spatial distribution of the administrators and fences.

Liu *et al.* [21] confirmed that emotional contagion can produce herd behaviour causing people to follow others and form a group during an evacuation. They concluded that emotional contagion could exacerbate panic in the crowd, causing the crowd to gather at a bottleneck and cause congestion. Fortunately, the integration of third-party authorities during an evacuation, such as security guards guiding individuals and teachers leading their students to safe egress and calmness [22], improve efficiency through minimized chaos among evacuees and reduce evacuation duration [2]. A minimum ratio of 1 authority to 35 people is highly recommended to optimize emergency rescue [23]. The experiments substantiated that the presence and strategic location of administrators or third-party authorities can effectively control the emotional contagion in the crowd and maintain the queue.

In observing the impact of familiarity of the place and habitual preference, the simulation results of Song *et al.* [24] showed that people with better knowledge usually have higher evacuation efficiency. However, this may not be the case in an earthquake context where logical thinking of an individual significantly decreases. The evacuees' initial actions are usually intuition-based and learned from experience, learning, and accumulated knowledge. Hence, habitual path, tried and tested on a daily basis, is their preferred option regardless of the route length. This may be advantageous due to a quick response if the need arises, but may be detrimental to the evacuation efficiency if the perception of the environment is inaccurate [24]. Chu *et al.* [25] simulated building egress of agents individually, by group and as a crowd with the following behaviours. When the state of high evacuation urgency is reached, the agent adopts various behaviours to escape from the building depending on the agent types. Agents classified as frequent visitors stick to their spatial knowledge of the closest possible exit while agents classified as occasional visitors stick to their spatial knowledge of the main entrance. Agents of type first-time visitors follow the majority of surrounding agents. In the event that no neighbouring agents are visible, navigation objects such as signages will serve as their guide.

3.2. Demonstrating Factors that can be considered for the Decision Support

Typically, the 'Nearest exit' scenario is the best policy for evacuation [7]. Carrera *et al.* [26] expounded this by identifying three ways or policies for leaving the building based on the exits: i) nearest gate wherein the exits could be the fastest but not necessarily the safest way (e.g. fire could be along the way to the gate), ii) safest gate, in the context of fire, the occupants vacate the building premises through the farthest exit from the onset point of the fire, and iii) less crowded gate where the occupants may either be rapidly assessing the other people's decisions or utilizing the spatial information of the building and opts to use the less crowded gate. They pointed out that though the gate may be safe, the path going to the safest gate may be dangerous.

A safe evacuation was demonstrated by Tytko *et al.* [27] using increasing crowd density which reached its maximum as the exit is approached. This maximum density value, 5.4 individuals per square meter [28], denotes the moment when human agents depart from the establishment via the exit point. This moment is immediately followed by a decrease in density. This turbulent trend, known as the 'stop-and-go flow' phenomenon [29], is common to many crowd disasters [30].

Liu and Deng [31] investigated path planning strategies for aircraft evacuation and concluded from their experiment results that balancing the number of passengers in each exit can decrease the evacuation time. This is made possible by the presence of flight attendants guiding the passengers and thus demonstrates the significance of guided evacuations in reducing the number of casualties. However, the authors mentioned that the downside of switching exits is the potential delay in transferring from one gate to another. They proposed a workaround by increasing the threshold of queue length difference which dramatically reduced the evacuation time.

Carrera *et al.* [26] observed that the time of day when evacuation occurs is another factor affecting evacuation duration. This factor was based on the implication that the number of people present in a structure will vary depending on what time a disaster will occur. Takabatake *et al.* [32] also looked into the impact of time of the day and found out that a large number of casualties would arise if the earthquake was to occur at night in Tofino, Vancouver Island, Canada. The authors also pointed out the importance of building management having the capability of assisting all evacuees, especially those with special needs such as the elderly. In addition, the authors suggested that the influence of evacuation start time and path choices on the mortality rate would vary substantially according to a scenario regardless of the study area.

Choi and Do [7] showed that the delivery of information (e.g. location and distribution of safe zone or shelter) to evacuees can significantly reduce the evacuation duration. Sugie *et al.* [33] found out that even if an evacuation route is lengthened probably due to the sudden presence of obstacles (e.g., falling debris), the total evacuation duration can be managed with proper guidance with around 10% of student agents more rapidly escaped that without guidance.

4. Preliminary Work

4.1. Adaptive Building Evacuation Simulation and Decision Support Framework

The preliminary adaptive building evacuation simulation and decision support framework, as shown in Figure 4, is composed of three (3) main components namely 1) the formulation of the cognitive agent model, 2) the evacuation simulation and 3) the decision support.

The formulation of the cognitive agent model, as the first framework component, starts with the design and execution of an online earthquake evacuation behavioural survey to the population of the case study site. The survey contains sections specifically demographics (D), experiences on earthquake and evacuation drills (Exp), dimensions of personality and survival-oriented personality (P), and emotions (Em) and behavioural decision-making (B). The results of the survey are then processed using cluster analysis (CA) and structural equation modelling (SEM). CA will classify and produce the evacuee archetypes which will be applied to the Behavioural Modification Approach experiments. These experiments will be presented in the succeeding publication of this study. SEM will confirm the cognitive agent model conceptual framework suggesting that D and Exp may affect an individual's P, P and the presence of a disaster situation (S) may affect a person's Em, and P, Em, and S may affect one's B. This component is implemented mainly in IBM SPSS Statistics and AMOS software.

The evacuation simulation, as the second framework component, is implemented using Unity game development software. Unity already contains a built-in physics engine which is a vital capability to make gravitational force act on the furniture and collision act among evacuees, furniture and other physical constraints. Such complex built-in capabilities enabled in the user interface and can be easily modified are not available on some simulation software such as GAMA. The simulation engine requires five (5) inputs namely 1) the 3-dimensional environment, 2) case study-specific scenarios, 3) the formulated cognitive agent model, 4) the methods for the agent perception and navigation, and 5) if available, the existing case study site evacuation strategies and plans. The 3D environment (some of the busiest portions in the building shown in Figure 3) includes all indoor furniture as these may add to the potential congestions which will affect the evacuation efficiency and total egress time. An agent population of up to 4000 is expected to be included in the evacuation simulation runs.

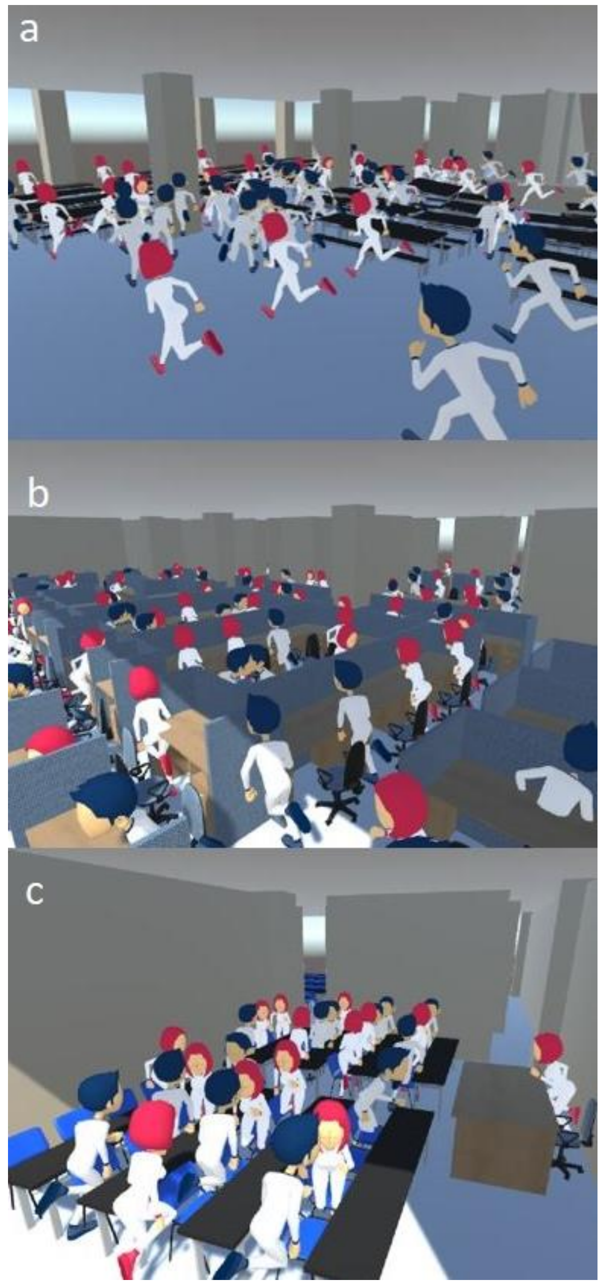


Figure 3. The 3D Environment with some of the Busiest areas in the building: a) canteen, b) faculty area and c) classroom

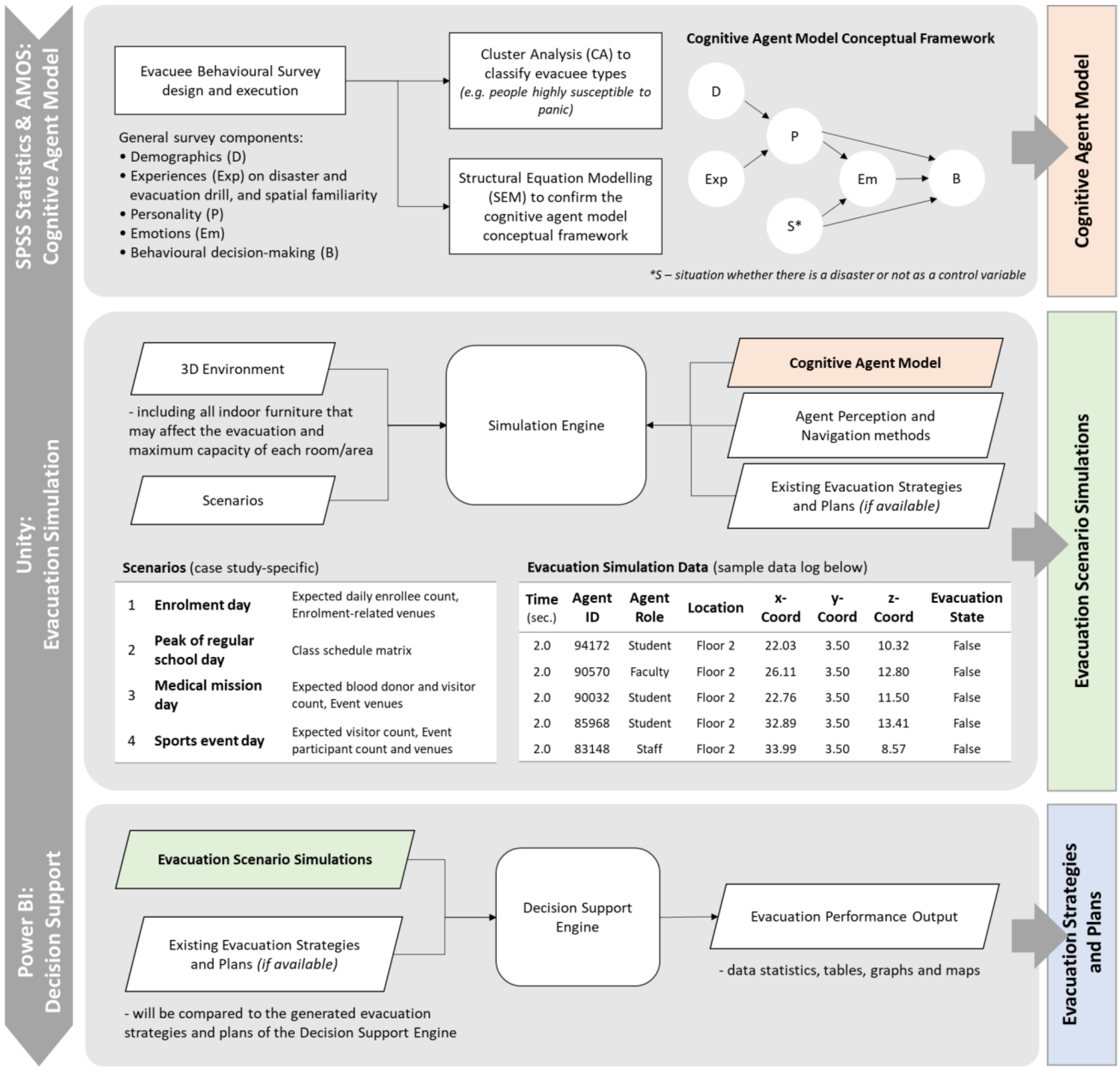


Figure 4. Preliminary Adaptive Building Evacuation Simulation and Decision Support Framework

The maximum capacity of each area and room were gathered as well as this will serve as the worst-case scenario with respect to the evacuee count. Moreover, the nearby assembly area and open spaces were delineated.

For the case study-specific scenarios, four (4) crucial scenarios were identified through consultations with the university representative as follows:

- Scenario 1: Enrolment day
- Scenario 2: Peak of a regular school day
- Scenario 3: Medical mission day
- Scenario 4: Sports event day

The output from the evacuation simulation component is a series of evacuation simulation data logs for each scenario. These include the time elapsed in seconds, agent ID, agent role, location, x, y and z coordinates, and the agent evacuation state. The agent-related data will be further discussed in the following subsection.

The decision support, as the third framework component, requires the evacuation scenario simulation results and if available, the existing case study site evacuation strategies and plans as inputs. The decision support engine contains the evaluation criteria and visualisations to produce a comprehensive evacuation performance output presented as tables, graphs and maps and corresponding proposed evacuation strategies and plans. This component is done in Power BI software which offers a wide range of user-friendly visualisations, built-in user interactions and customisation through programming languages such as Python and R.

4.2. Agent Attributes and Activity Diagram

The preliminary set of agent attributes, as summarized in Table 1, includes uniquely generated ID number, role whether faculty, staff, student, or safety- and medical-related personnel, attributes such as age bracket and gender that may affect the evacuation performance due to any cognitive differences that can be derived from the results of the conducted survey. The location attribute involves the simulation object where the agent is currently situated, for instance, the floor level, stairs in between two floors, and assembly area. In addition, the instantaneous x, y and z coordinates are recorded as well. Lastly, the evacuation state confirms whether an agent already has arrived in the evacuation assembly area or not. These spatial attributes will be used to map any crowd congestions at any time elapsed during the evacuation.

Table 1. Preliminary set of Agent Attributes in relation to Evacuation Simulation Data and Cognition

Agent Attribute	Description
ID	generated unique number ID
Role	role in the simulation (e.g., faculty, student)
Age bracket	may imply cognitive differences based on the conducted survey
Gender	may imply cognitive differences based on the conducted survey
Location	current location (e.g., 2nd floor, stairs, assembly area)
x-Coord	coordinate along x-axis
y-Coord	coordinate along y-axis
z-Coord	coordinate along z-axis
Evacuation state	True if the agent has arrived in the assembly area; False if otherwise

Figure 5 illustrates the preliminary agent activity diagram involving faculty and student roles. The activities for faculty members and students correspondingly fall under their respective columns while activities on the column border are applicable to both roles. The activities are based on the evacuation protocol of the university case study site. Those delineated with dash lines involve cognitive aspects derived from the conducted online earthquake evacuation survey. The activity flow starts with the identification of the initial situation whether a faculty member is currently supervising a class or not, and whether a student is currently under a supervision of a faculty (e.g., classes are ongoing) or otherwise.

Within the two (2) major parts of the activity diagram separated with the grey synchronisation bars (fork/join), activities with cognitive aspects derived from the survey contain the conditions 1) if not sure of the escape route, and 2) if the path is congested. The action for condition 1 can be selected from the options "Look for the emergency escape map", "Follow my instinct and look for an alternative route", and "Follow the majority". For condition 2, the action can be "Look for an alternative route at the opposite direction", "Look for an alternative route only if the opposite direction is not crowded", "Wait for the congestion to subside", "Attempt to calm the crowd", and "Stay patient and follow the crowd".

On the side of the faculty member, if he/she is currently handling a class during the onset of a disaster, he/she then instructs the students to proceed with the standard procedure for an earthquake situation which is to duck, hold and cover under a table or chair. Once the earthquake subsides, he/she then decides to move to the closest door in a classroom or laboratory to see whether if it is already safe to evacuate. If yes, the faculty instructs and leads the students to form a single line and commence the evacuation towards the stairs if the current floor level is the second floor and above. He/she then moves to the end of the line to check whether there is any student left behind. After checking, he/she proceeds along the middle of the line to oversee the students while evacuating. If the faculty member does not have a class or set of students to supervise at the onset of the earthquake, he/she may either approach the nearest student/s to assist them during the evacuation or proceed with the evacuation even while the earthquake is ongoing. This may sound irrational, but this type of behaviour can be commonly observed in earthquake footages especially in public places such as a mall and a concert venue.

On the other hand, the student's situation is initially determined whether he/she is under a supervision of a faculty member during the onset of the earthquake or not. If yes, he/she follows the instructions of the faculty

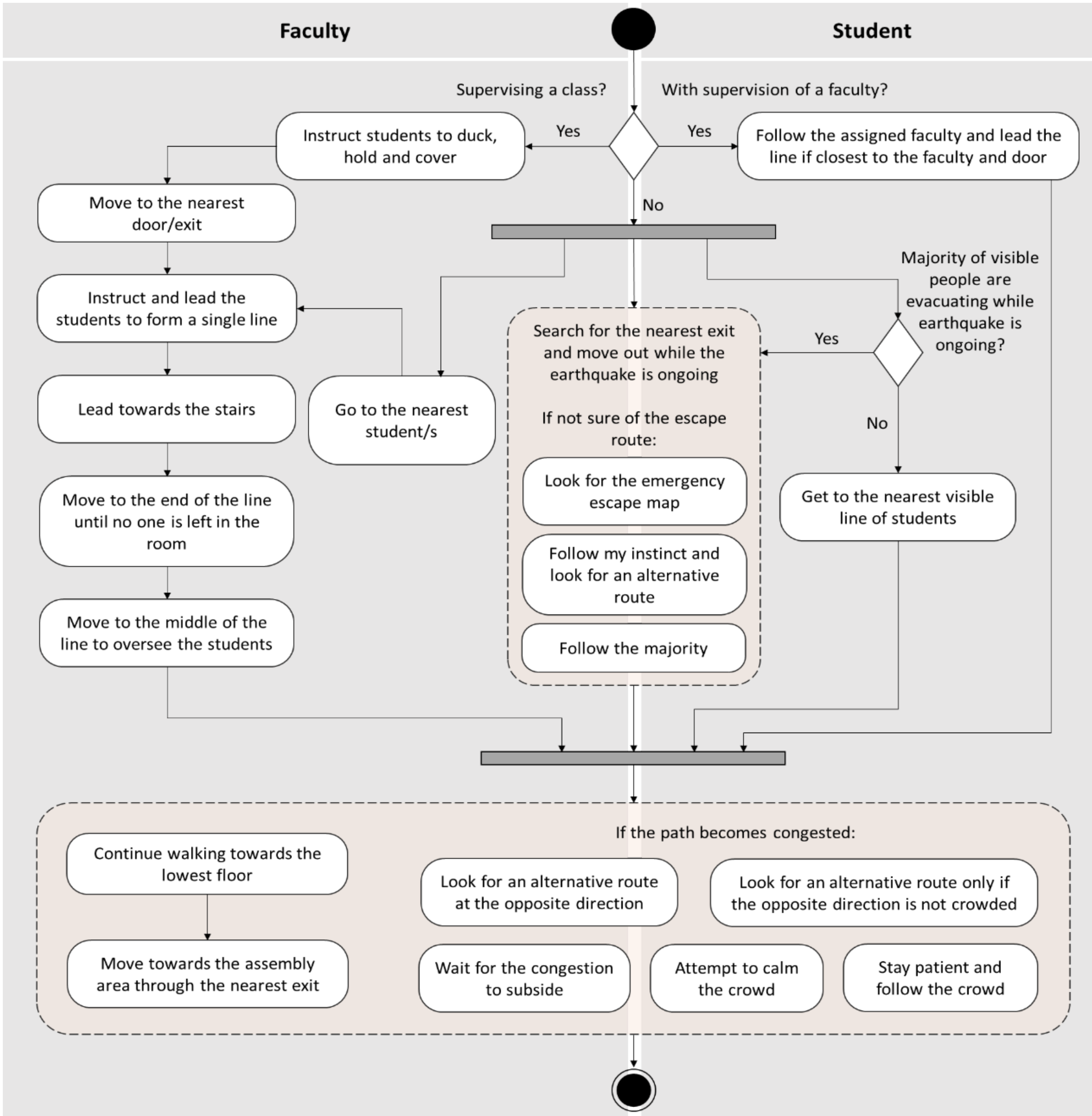


Figure 5. Preliminary Agent Activity Diagram involving faculty members and students

member and leads the single-file line of his/her class if he/she is the closest to the faculty member and the classroom or laboratory door. If not, he/she may be in a position wherein most of the people within his/her view are evacuating even while the earthquake is ongoing or otherwise. The student may opt to be tagged along with these people and follow them or get to the nearest visible line of students to evacuate calmly and safely.

All evacuees then continue to move downstairs until the assigned or nearest exit is reached towards the assigned or nearest assembly area.

5. Conclusion and Future Work

This paper reviewed the works on cognitive aspects affecting evacuation performance, and factors that can be considered for the decision support with a focus on the agent-based approach. A proposed adaptive building evacuation simulation and decision support framework composed of three main components namely the formulation of the cognitive agent model, the evacuation simulation, and the decision support were illustrated and explained in detail. Further, the preliminary set of agent attributes in relation to evacuation simulation data and cognition, and agent activity diagram involving faculty members and students were described as well. The timeliness of the research in the Philippine context of the long-overdue "Big One" earthquake, the vulnerability of the case study, and the capability of the framework to be a standard guide where components can be customized by users based on the disaster type and site-specific requirements such as evacuation protocols make this research a significant undertaking.

Four contributions of this study were presented. First, a detailed representation of agents representing the university population that takes into account demographics, experiences on earthquake and evacuation drills, dimensions of personality and survival-oriented personality, emotions, and behavioural decision-making. There are existing evacuation simulation with decision support systems such as the work of Marzouk and Mohamed [4]. However, their focus is on the integrated system and suggested incorporation of detailed human behaviour to produce a more realistic approach. Second, the implementation of the behavioural modification approach as the foundation for efficient evacuation given that this approach is still underexplored and offers a great potential [5]. Third, the application of the evacuation simulation on a multi-storey building in a 3D environment as simulation approaches and behavioural models have so far been applied in single-storey spaces and more attention must be given to such complex structures [7, 8, 9]. Lastly, the provision of a decision support tool that will evaluate existing and propose new evacuation plans and strategies, adapting to the dynamics of agents' evacuation performance.

There will be several future publications as soon as the results from the following works have been completed. Work has been commenced on finalising the set of agent attributes including the possible presence of any medical condition that may hinder an individual's evacuation [8]. The earthquake evacuation survey will then be fully introduced and the results from CA and SEM will be interpreted and adapted to the agent model. The evacuee archetypes that will be derived from CA will be employed in a series of simulation experiments varying the percentages of these archetypes to explore the effect of Behavioural Modification approach to the evacuation performance and efficiency. The experiments will be accompanied with more visualisation snapshots from Unity with the evacuation statistics illustrated in graphs and maps (e.g., heat map, route map). Furthermore, the construction of the decision support component of which the focus is to set the criteria for the evaluation and generation of modified or proposed evacuation scheme will be presented.

6. Acknowledgements

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7. References

[1] McLoughlin, D., "A framework for integrated emergency management", *Public administration review 45*, 1985, pp. 165–172.

[2] Chu, M.L., and K.H. Law, "Incorporating Individual Behavior, Knowledge, and Roles in Simulating Evacuation", *Fire Technology 55*(2), 2019, pp. 437–464.

[3] Souza, J.C., A.W. Schumann, M.L. Nappi, et al., "The Importance of Architectural Design in Disaster Mitigation Involving Crowds", Springer International Publishing (2020), 87–95.

[4] Marzouk, M., and B. Mohamed, "Integrated agent-based simulation and multi-criteria decision making approach for buildings evacuation evaluation", *Safety science 112*, 2019, pp. 57–65.

[5] Haghani, M., "Optimising crowd evacuations: Mathematical, architectural and behavioural approaches", *Safety science 128*, 2020, pp. 104745.

[6] Sharma, S., H. Singh, and A. Prakash, "Multi-agent modeling and simulation of human behavior in aircraft evacuations", *IEEE Transactions on aerospace and electronic systems 44*(4), 2008, pp. 1477–1488.

[7] Choi, S., and M. Do, "Effect of Evacuation Information and Evacuation Behaviors on High-Rise Apartment Residents", *KSCE Journal of Civil Engineering 23*(11), 2019, pp. 4886–4897.

[8] Rendón Rozo, K., J. Arellana, A. Santander-Mercado, and M. Jubiz-Diaz, "Modelling building emergency evacuation plans considering the dynamic behaviour of pedestrians using agent-based simulation", *Safety science 113*, 2019, pp. 276–284.

[9] Sun, Q., Y. Turkan, I. Mutis, and T. Hartmann, "A BIM Based Simulation Framework for Fire Evacuation Planning", Springer International Publishing (2019), 431–438.

[10] United States Geological Survey, "Ring of Fire", *Earthquake Glossary*. https://earthquake.usgs.gov/learn/glossary/?term=Ring of Fire

[11] Galvez, D., and J. Alipala, "7.1-magnitude quake jolts sea off Davao", *2020*, 2018. https://newsinfo.inquirer.net/1067508/7-1-magnitude-quake-rattles-sea-off-davao

[12] S&T Media Service, "Prepare for 'The Big One': Dost Makes Valley Fault Atlas Available Online", 2016. http://www.dost.gov.ph/knowledge-resources/news/45-2016-news/906-prepare-for-the-big-one-dost-makes-valley-fault-atlas-available-online.html

[13] DOST-PHIVOLCS, "Earthquake Monitoring",

Philippine Institute of Volcanology and Seismology (PHIVOLCS) Web site 2020, 2018. https://www.phivolcs.dost.gov.ph/index.php/earthquake/earthquake-monitoring

[14] Philippine Institute of Volcanology and Seismology, "Philippine Fault System Map",

[15] GeoRisk Philippines, "HazardHunterPH", https://hazardhunter.georisk.gov.ph/

[16] Google, "Google Maps vicinity of National University Manila Campus",

[17] Mao, Y., X. Du, Y. Li, and W. He, "An emotion based simulation framework for complex evacuation scenarios", *Graphical Models 102*, 2019, pp. 1–9.

[18] Bourgais, M., P. Taillandier, L. Vercouter, G.P. Dimuro, and L. Antunes, "Enhancing the Behavior of Agents in Social Simulations with Emotions and Social Relations", Springer International Publishing (2018), 89–104.

[19] Liu, B., Z. Liu, D. Sun, and C. Bi, "An Evacuation Route Model of Crowd Based on Emotion and Geodesic", (2018).

[20] Xue, J., H. Yin, P. Lv, M. Xu, and Y. Li, "Crowd queuing simulation with an improved emotional contagion model", *Science China Information Sciences 62*(4), 2019, pp. 44101.

[21] Liu, T., Z. Liu, Y. Chai, et al., "Modeling Emotional Contagion for Crowd in Emergencies", Springer International Publishing (2019), 161–168.

[22] Mao, Y., S. Yang, Z. Li, and Y. Li, "Personality trait and group emotion contagion based crowd simulation for emergency evacuation", *Multimedia Tools and Applications 79*(5), 2020, pp. 3077–3104.

[23] Faroqi, H., and M.-S. Mesgari, "Agent-based Crowd Simulation Considering Emotion Contagion for Emergency Evacuation Problem", *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, (2015), 193–196.

[24] Song, Y., K. Xie, and W. Su, "Mechanism and strategies of post-earthquake evacuation based on cellular automata model", *International Journal of Disaster Risk Reduction 34*, 2019, pp. 220–231.

[25] Chu, M.L., P. Parigi, K.H. Law, and J.-C. Latombe, "Simulating individual, group, and crowd behaviors in building egress", *Simulation 91*(9), 2015, pp. 825–845.

[26] Carrera, Á., E. Merino, P. Aznar, et al., "An Agent-Based Simulation Model for Emergency Egress", Springer International Publishing (2019), 140–148.

[27] Tytko, K., M. Mamica, A. Pękala, et al., "Simulating Pedestrians' Motion in Different Scenarios with Modified Social Force Model", Springer International Publishing (2020), 467–477.

[28] Weidmann, U., and T. Institut für Verkehrsplanung Strassen- und Eisenbahnbau (IVT), ETH Zürich, *Transporttechnik der Fussgänger*, 1993.

[29] Yu, W., and A. Johansson, "Modeling crowd turbulence by many-particle simulations", *Physical review E 76*(4), 2007, pp. 46105.

[30] Moussaïd, M., D. Helbing, and G. Theraulaz, "How simple rules determine pedestrian behavior and crowd disasters", *Proceedings of the National Academy of Sciences 108*(17), 2011, pp. 6884.

[31] Liu, D., and X. Deng, "Investigating the Strategy on Path Planning on Aircraft Evacuation Process Using Discrete Event Simulation", *Mobile Networks and Applications*, 2020.

[32] Takabatake, T., I. Nistor, and P. St-Germain, "Tsunami evacuation simulation for the District of Tofino, Vancouver Island, Canada", *International Journal of Disaster Risk Reduction 48*, 2020, pp. 101573.

[33] Sugie, R., T. Uchiya, I. Takumi, L. Barolli, F. Xhafa, and J. Conesa, "Investigation Using Multi-Agent Simulation Environment for Evacuation Guidance with Robots", Springer International Publishing (2018), 834–843.