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Implementation of Agent-Based Modelling to Observe the Evacuating Behaviour at Faculty of Engineering Building, University of Bengkulu, Indonesia

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ABSTRACT Evacuation is an important issue during the occurrence of an earthquake, due to the influence of people's responsive behaviours to the disaster. This indicates the occurrence of overcrowded conditions, which causes the conflict of people's movement. It is also one of the main reasons the process of evacuation is difficult, leading to the necessity to specifically model the movement within each building. Therefore, this study aims to analyze the earthquake evacuation modelling in Faculty of Engineering building, University of Bengkulu, Indonesia. This used a multi-agent programmable modelling environment known as NetLogo, which adopted an ABM model that is often utilized to observe elemental movement response. The agents occupying the building also moved to the stairs and evacuation doors, for exit towards the assembly point, which was located in front and behind Faculty of Engineering. The agent-based modelling is then conducted by inputting the layout of the building and the number of occupants in each room. Furthermore, the simulations were performed by considering various agents' capacity in the building, during the evacuation. The results showed the time taken for the agents to exit the building during the disaster. This confirmed that the required exit time generally decreased with the increasing population percentage in the building. During this process, the conflict point also occurred around the corridor of Floors 1 and 2 (T1, T2 and T3), as well as the exits of the building (P1, P2, P3, and P4). This was due to the occurrence of a high density when agents carry out evacuation movements. Based on these results, the placement of signs was recommended, as guidelines during the evacuation process.

KEYWORDS Earthquake; Evacuation; Agent-Based Modelling; Evacuation Sign; Agent Movement

1 INTRODUCTION

Sumatra Island is an earthquake-prone area crossed by an active fault along the mountainous Bukit Barisan known as Sumatra Fault (Lay et al., 2005). On the west side of the island, the subduction zone causing many earthquakes events is observed, with Bengkulu found to be one of the numerous cities commonly experiencing these disasters. This is because the location of the city is at the confluence of the Indian Ocean and Asian tectonic plates, subsequently causing the proneness of earthquakes and tsunamis (Mase, 2021), as presented in Figure 1. Within the previous decades, the occurrence of two strong earthquakes (2000 and 2007) led to a major impact on Bengkulu City (Mase, 2020). These were known as the Mw 7.9/8.6 Bengkulu-Enggano and Bengkulu-Mentawai Earthquakes in 2000 and 2007, respectively (Mase et al., 2021). According to Mase (2018) and Misliniyati et al. (2018), many infrastructural buildings, such as government complexes, housing areas, public facilities, and academic institutions experienced the impact of earthquakes, with Farid and Mase (2020) also stating that seismic hazard mitigation should be completely performed with no exception, to minimize the effects of the disaster. In addition, one of the critical issues observed during this hazardous event is the effort in the evacuation process.

During the occurrence of strong earthquakes in Bengkulu City, one of the most impacted areas was

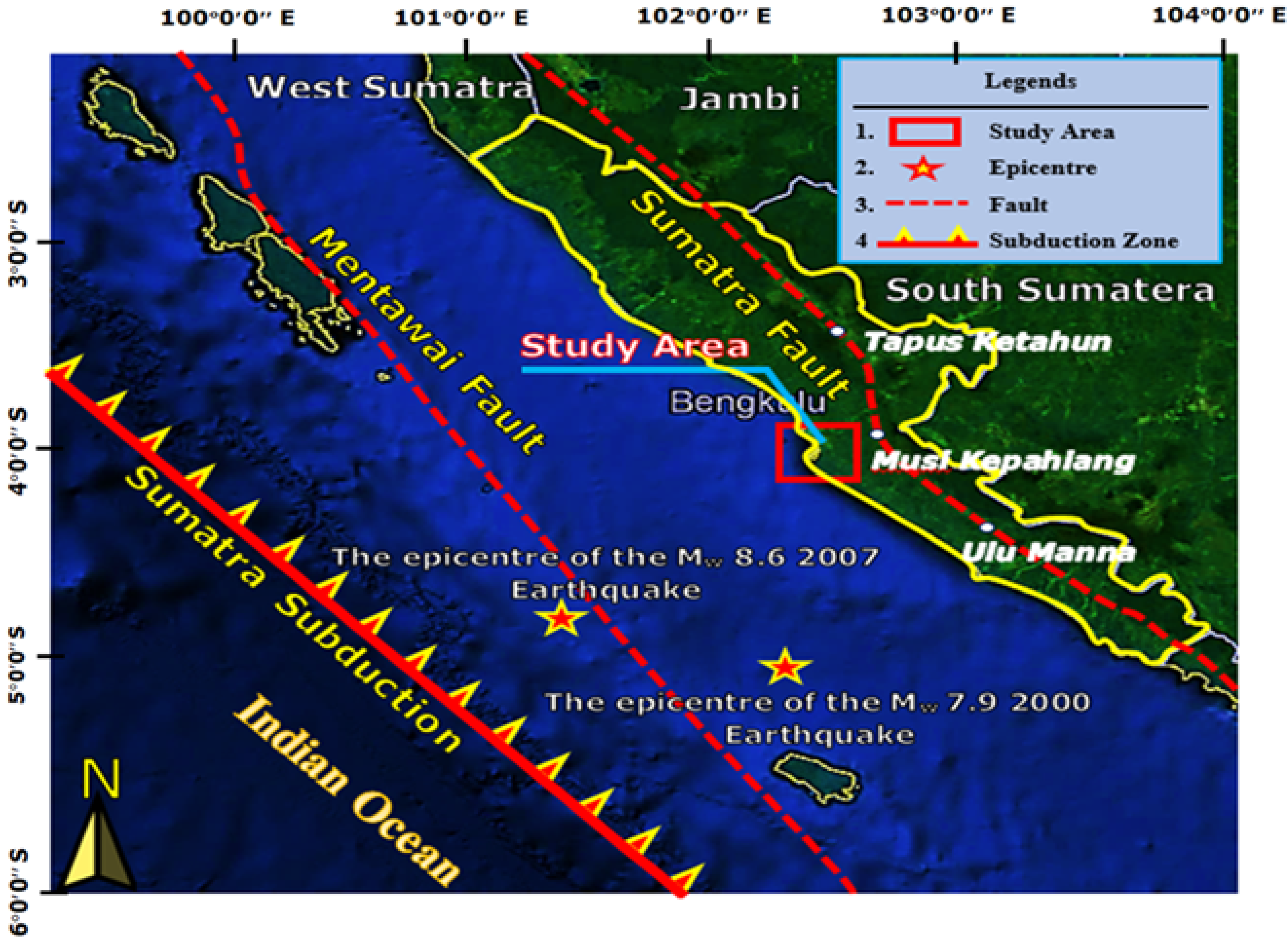


Figure 1 The seismotectonic setting of Bengkulu (Mase, 2021)

University of Bengkulu, where several buildings had reportedly collapsed. This is located in an urban area with high social activity, due to being the biggest institution within the province. The existence of academic activity also needs to be accompanied by a better understanding of earthquake evacuation patterns. At the university, Faculty of Engineering building serves as the academic activity for educational citizens, such as students, lecturers, scholars, and administration staff. Hundreds of people are often located in this building for daily academic activities, such as teaching, reports, and community services. This led to the assumption that the facility occupants are likely to panic during the evacuation, based on the occurrence of a strong earthquake. In addition, the information related to evacuation lines and access is still limited in the building, regarding the initial observations. Under the existing facility condition, study experts were promoted to emphasize Faculty of Engineering as an analytical object, to model the movement of agents during an earthquake evacuation process.

To model the evacuation process, many methods were widely introduced by various experts, with Edara et al. (2010) employing the VISSIM and VISUM to develop a large-scale traffic simulation module for hurricane evacuation. Hardiansyah et al. (2019, 2020) also used the traffic simulation and assignment in urban road networks (SATURN), to model vulnerabilities during the Merapi Eruption, Yogyakarta, Indonesia. These methods are generally implemented for complex cases, with the consideration of many analytical parameters. However, the Agent-Based Modelling (ABM) was implemented for simple cases based on limited data, such as evacuation routes. This is a modelling approach used to realistically analyze complex systems (Kasereka et al., 2018), where three factors are observed to initiate the emergence of methods, namely (1) the emergence and development of computers, (2) the awareness of the need for complexity, and (3) the un-

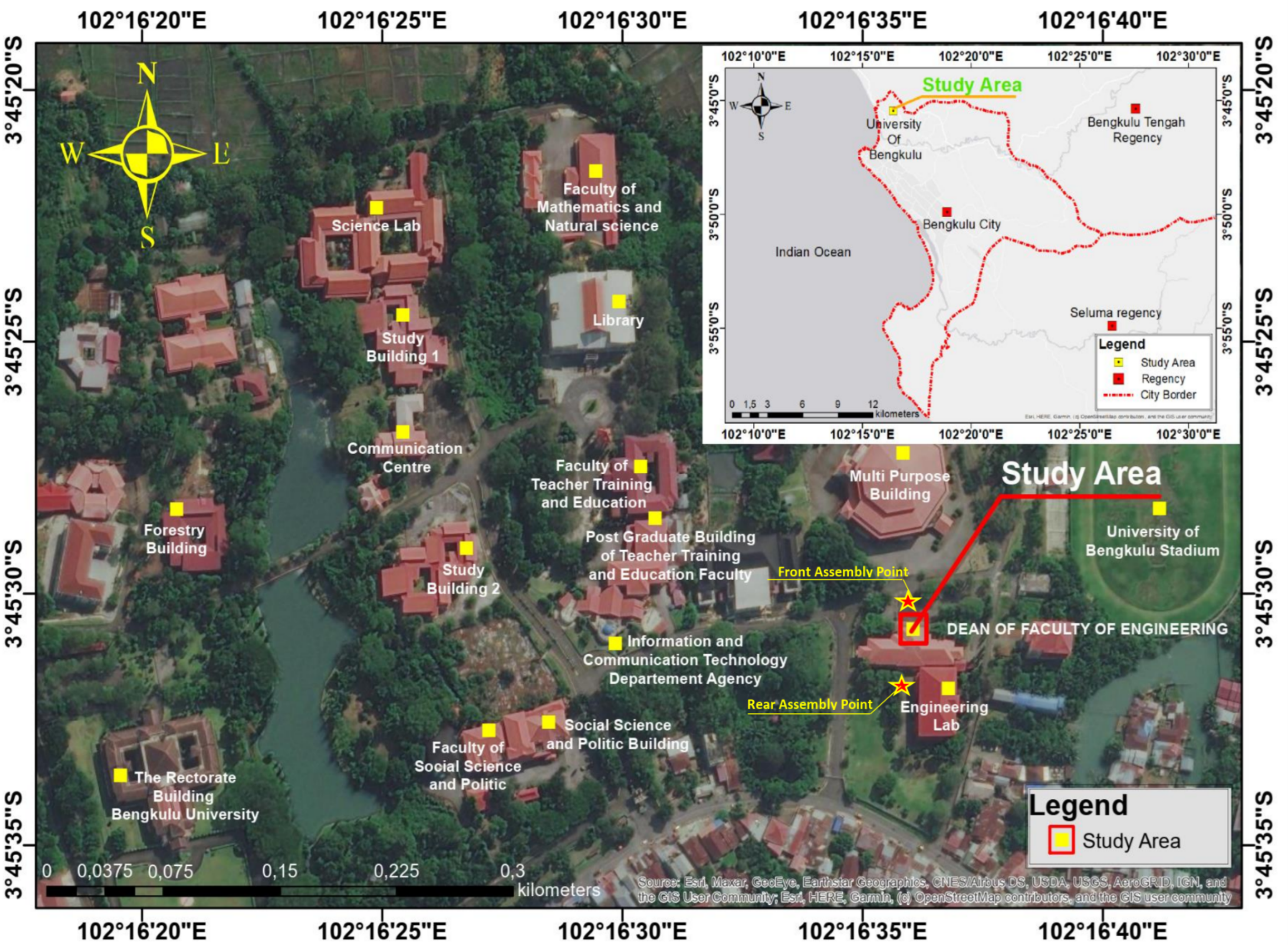


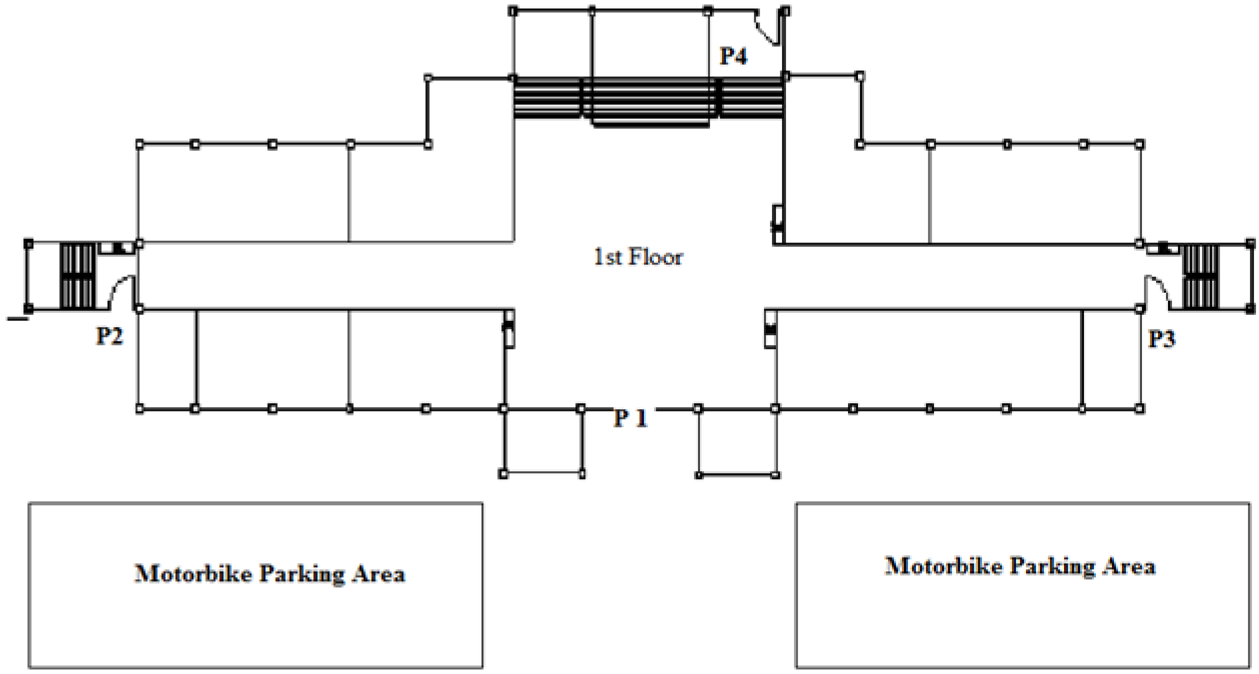
Figure 2 Location of Faculty of Engineering building (Google Earth, 2021)

derstanding of the system. ABM is also a great choice for present problem-solving alternatives in complex systems, due to being used in describing the behaviour of agents during direct observable movements (Railsback and Grimm, 2019). In some previous studies, this model was implemented for several buildings' evacuative simulations within the University of Bengkulu. Based on Pratama et al. (2020) and Nabila et al. (2020), the model to observe the evacuation characteristics of agents was implemented during the tsunami events in some external buildings. This proved that ABM revealed some potential conflict areas during the evacuation processes, recommending the enhancement of several alternative roads in the institution. These reviews showed that no report has been performed on the implementation of this model, based on the prediction of the agents' movement from the building to the assembly areas. Therefore, this study aims to evaluate the implementation of ABM, to observe the movement response of agents during earthquake evacuation. The results are also expected to be used as a mitigation guideline and an overview of the movement response of agents, based on the evacuation of the disasters within Faculty of Engineering building.

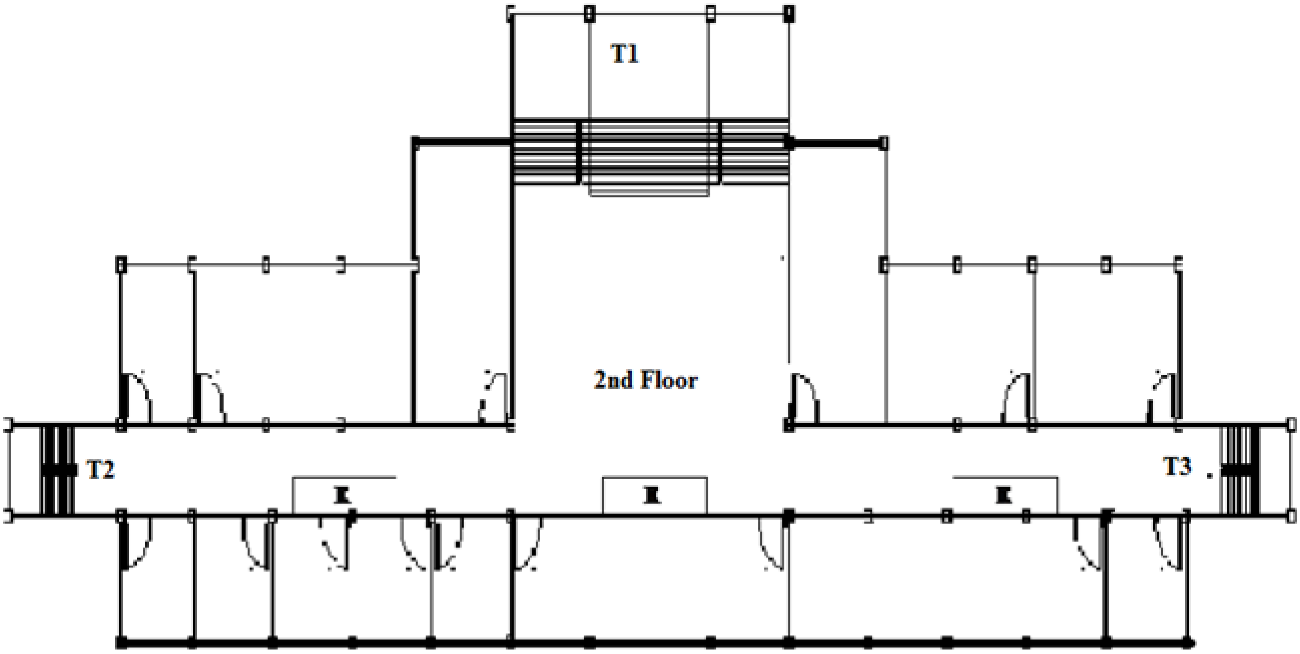
2 BACKGROUND THEORY AND METHOD

2.1 Study Area and Situation of Agents in Faculty of Engineering Building

The reviewed study area is Faculty of Engineering building, University of Bengkulu, Indonesia, which serves various academic activities for several educational citizens. Therefore, the evaluation of the evacuation modelling of agents within this building is found to be very important. This facility is located at WR. Supratman Road, Kandang Limun Village, Muara Bangkahulu District, Bengkulu City, Indonesia, as shown in Figure 2. The building layout is also presented in Figure 3, where the first and second floors are observed (Fig-



(a) First floor



(b) Second floor

Figure 3 Room layout of Faculty of Engineering building (archive of University of Bengkulu, 2021)

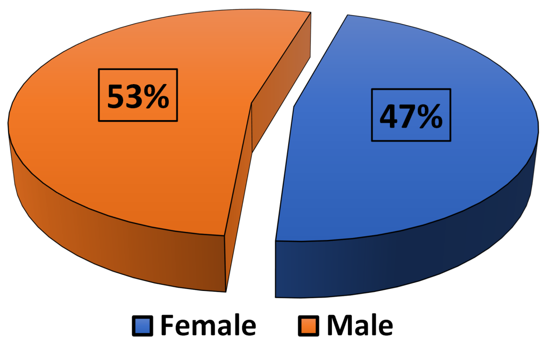
ures 3a and 3b). In Figure 3a, the following are also observed, (1) the main door (P1), (2) the door on the left side (P2), (3) the door on the right side (P3), and (4) the postern (P4). Meanwhile, the main staircase (T1), as well as the left and right stairways (T2 and T3) are shown in Figure 3b. On the first floor, the academic and student affairs department, as well as four major offices were found, with the faculty and vice deans' rooms observed within the second platform, where the meeting hall, senate room, and two major offices were also located.

To obtain the distribution of agents in Faculty of Engineering building, a survey was conducted from 15 to 17 June 2020. Based on the preliminary survey, the total agents within this building were 250 people, including permanent (lecturers, scholars, and administrative staff) and non-permanent (students and visitors) agents. Regarding gender and age, the results are presented in Figure 4, where 53% male and 47% female were observed (Figure 4a), with 87, 9, and 4% agents being 19-25, 26-40, and 41-60 yrs old, respectively (Figure 4b). This confirmed that the population of agents was dominated by students, based on the age category. It also reflected that most of agents are categorized as non-permanent, as presented in Figure 4c.

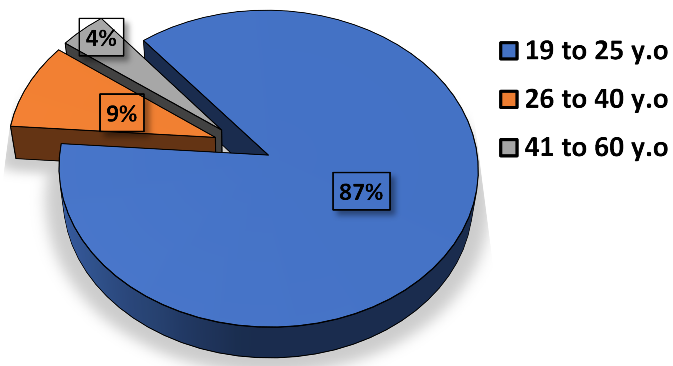
2.2 Urgence of evacuation and ABM concept

The earthquake that occurred in the Sumatra region was the original vibration within the earth. The causes of these disasters are often based on the dynamics of the earth, volcanic activity, falling meteors, or landslides below sea level (Hinga, 2015). According to Arai et al. (2016), the sudden movement of two plates was found to cause earthquakes and tsunamis (Ishii et al., 2005). This indicated that these natural vulnerabilities encompassed the entire west coast of Bengkulu Province, an earthquake-prone area. It also showed that the people living in earthquake-prone areas need evacuation knowledge for self-rescue, due to the movement of communities to a safe and non-hazardous area (Wood et al., 2016). Furthermore, three steps were adopted to reduce the impact of disasters, namely (1) understanding the vulnerability of disaster threats in an area, (2) understanding the region's vulnerability in constructing an early warning system, and (3) proneness to disaster maps (Putera et al., 2018).

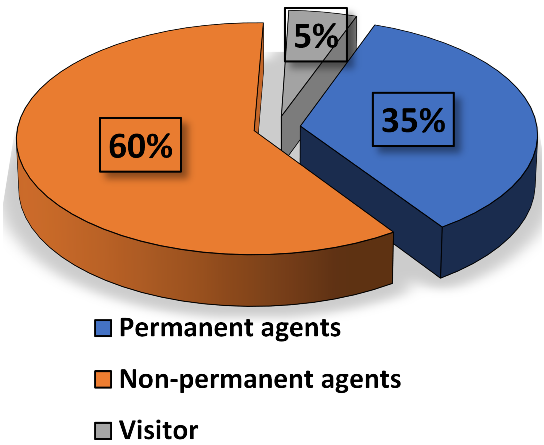
In the 1970s, Agent-Based Modelling was developed as a relatively simple concept, which had presently been integrated into the NetLogo computer program. This was initially used as a segregation dynamics model, which had presently undergone several developments. Its development includes the comprehension of agent interactive



(a) Based on gender



(b) Based on age



(c) Based on category of residence

Figure 4 Percentage of agents in Faculty of Engineering building movement at a location, subsequently leading to new properties. According to Khair et al. (2014), these new properties were not only concluded by combining the agents' characteristics. Nur (2010) also stated that the performed model analyses were boundary adequacy, extreme condition, and behaviour reproduction tests, respectively. The results revealed that improvements were obtained from the knowledge increase in evacuation training and routes. Based on the improvement of the scenario, an increase was observed in the number of agents that passed through to the assembly area, compared to the initial conditions. This process was carried out to determine several evacuation routes, for the direct extraction of the building occupants (Proulx, 2001). Based on these results, evacuation time needs to be faster than the eventual collapse of the building. In addition, a building should be able to maintain its condition for a specific required period, through the fastest evacuation route to a safe location. The considered travel time is also observed as the period required by the agent to exit the building towards the assembly area.

The advantage of ABM depends on the ability to model complex realistic systems, based on the agents' interaction. From this modelling, the emerging characteristics are related to the knowledge of agents' movement, evacuation interaction, etc (Sahroli and Hardiansyah, 2019). This is because the development of computational techniques is increasingly complex in building simulation systems. For crowd evacuation simulation, some studies generally used three categories of agent-based models. According to Tumewu (2017), these categories were (1) human evacuation with buildings, (2) crowd evacuation for urban highways, and (3) human crowd behaviours during evacuation. Helbing (2012) also showed that one of the properties of NetLogo was related to the stochastic nature of the modelling agent output, indicating that the obtained results always changed with an attempt to acquire evacuation time. Subsequently, evaluation is often carried out in two patterns, namely horizontal and vertical (Reyes and Miura, 2016). In the horizontal pattern, evacuation is needed based on the community carrying out the process on foot (Norio et al., 2011). Meanwhile, vertical evacuation explains that people often flee to a building with a specific height and strength, which is used as a shelter or to accommodate temporary agents during a sudden earthquake. The evacuation route is also a path used for the direct and rapid movement of people fleeing from threats or hazardous events. This is because agents are found to often perform instantaneous and simultaneous movements during the panic condition, which commonly leads to very high casualty levels. In hazardous conditions, preparedness is also the key to safety, due to being a series of activities carried out to anticipate disasters through adequate and appropriate organization, as well as efficient steps (Manandhar, 2016).

ABM is very effective in understanding the behavioural patterns of people during catastrophic threats (Janssen, 2005), due to being easier to simulate cognitive attitudes, such as events and causes of panic, heterogeneity of agents (Richiardi, 2017), and communication modes (Bonabeau, 2002). The advantage of this program depends on the ability to model reality into complex systems. It also produces complex system behaviour from the contained agents' interaction (Cegielski and Rogers, 2016), including the improvement of knowledge of evacuation routes and areas, understanding the movement and communication of people during extraction, etc. In this study, the measured evacuation time was the longest period acquired during the exit towards the assembly area. During the evacuation, the movement of agents was also obtained from the nearest stairs and doors to the assembly area. All agents were considered to know the evacuation route to the assembly point, with the scenario being conducted in a barrier-free state, where all doors and stairs were used to exit the building.

2.3 Study Framework

Figure 5 shows the diagrammatic representation of this study, which was initially conducted based on the problematic definition of seismic hazard mitigation importance at University of Bengkulu. In this condition, the experts focused on the evacuation modelling in Faculty of Engineering building within the institution. Before data collection, some literature related to evacuation, ABM, and questionnaire composition patterns were also reviewed. Furthermore, the collection of information was conducted to determine the primary and secondary data. These primary data included the

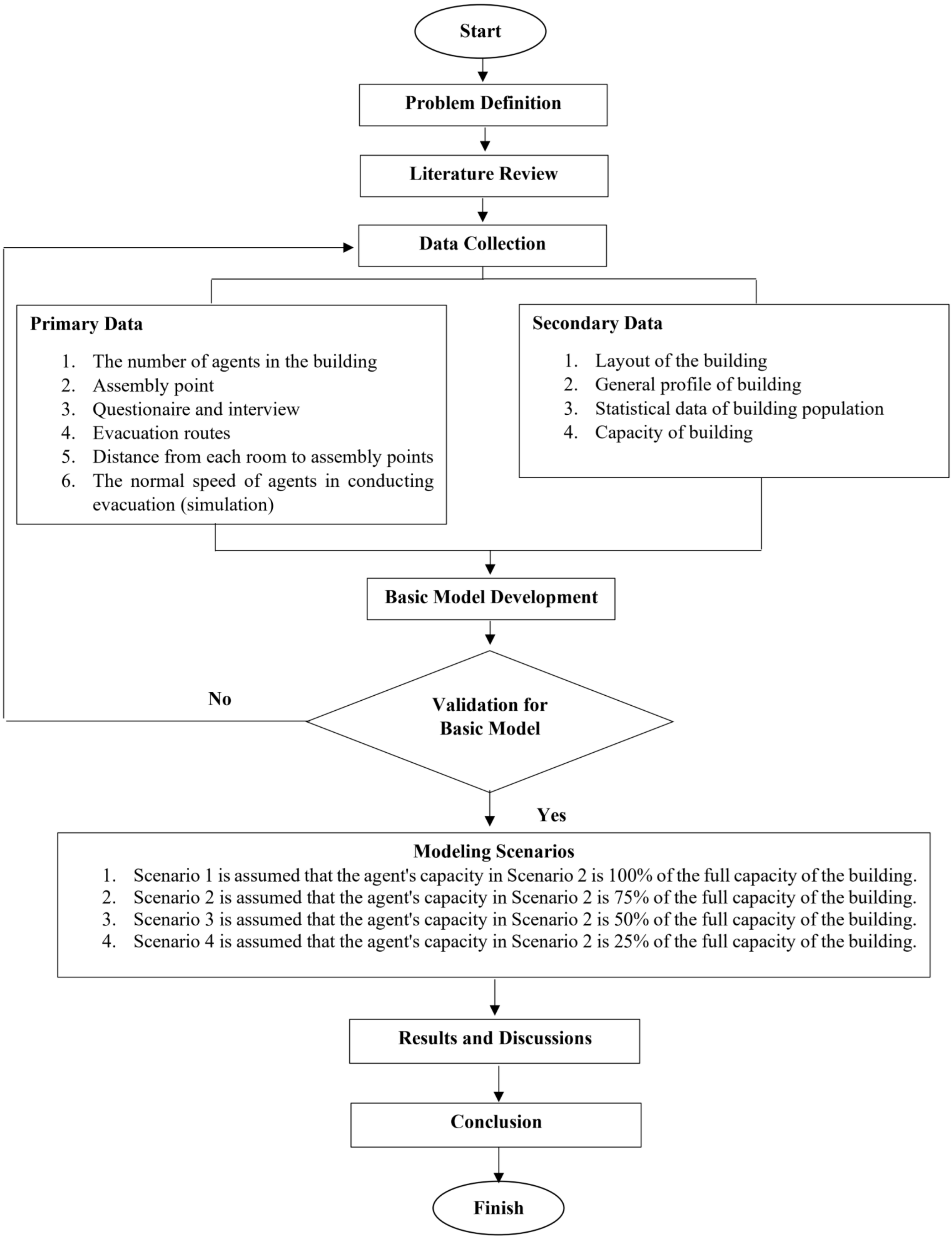


Figure 5 Study flow chart

number of building agents, assembly area position, questionnaire sheet, evacuation route, and the normal speed of people during extraction. Meanwhile, the secondary data included the building layout, general profile, statistical population parameters, and capacity. These data were then used to compose a basic model, which is preliminarily addressed to observe program performances. During an interview, a small simulation was conducted to obtain the time required to escape from the building, based on the assumed occurrence of an earthquake. This was accompanied by the ABM numerical simulation, to determine the required time for evacuation. However, the building damage effect and other scenarios such as aftershock and mainshock were not considered.

After the basic model development, validation was subsequently conducted through the linear regression analysis, to observe the consistency between the program and the simulation. To ensure the model reliability, the coefficient of determination (R^2) was also more than 0.7 (Nabila et al., 2020). In this condition, the process of data collection and basic model development was repeatedly performed and vice versa when the validation did not reach the minimum R^2. This was accompanied by the evacuation simulation process, where the population was highly considered due to being a whole set of elements with common characteristics. This contained the utilized experimental areas, which served as a whole group of people, events or items of interest to the experts. Therefore, the population is a whole set of elements used to create many conclusions. Slovin's (1960) equation which shown in Equation 1 was also used to determine the required sample size as follows:

$$n = \frac{N}{1 + N\left(e^2\right)} \tag{1}$$

where n N = the numbers of respondents and populations, respectively, and e = the percentage of leeway due to sampling errors.

To measure the consistency of respondents' answers, a Likert scale was used in measuring their respective attitudes and opinions. In this condition, respondents were instructed to complete a questionnaire, which required them to indicate their consent level to a series of statements, which were specifically referred to as defined variables.

Table 1. Likert's scale (Likert, 1932)

Category	Grade	Scoring Scale
Strongly disagree	1	0.00-0.99
Disagree	2	1.00-1.99
Agree	3	2.00-2.99
Strongly agree	4	3.00-4.00

The Likert (1932) scale was also used to measure the attitudes, opinions, and perceptions of a person or group of people on earthquakes, as respondents were required to indicate their level of agreement with a series of questions, which were specifically referred to as study variables. These agreement levels contained 4 scale choices, which categories ranged from SA-SD, indicating trongly Agree to Strongly Disagree, respectively, as shown in Table 1. In this condition, the Likert scale included SA, Agree, Disagree, and SD (scores 4, 3, 2, and 1). Moreover, the average answers were obtained from the total responses and multiplied by the score, which was then divided by the overall participants. This showed that the results SA, A, D, and SD with the question at the scores between 3.00-4.00, 2.00-2.99, 1.00-1.99, and 0.00-0.99, respectively.

For the ABM simulation, the measured evacuation time was agents' required travel period. This indicated the time taken for agents to exit the building towards the meeting point. While leaving the building, agents' behaviours were also observed based on the response to the earthquakes. This led to 4 different modelling scenarios to determine the travel time and conflict points when agents carry out evacuation movements away from the building,

1. Scenario 1: The modelling is conducted without changing the route and agents in the building. In this condition, agents' capacity in the building is assumed to be 100%.
2. Scenario 2: Agents' capacity is assumably 70% within the building.
3. Scenario 3: The capacity is assumed to be 50% in the building.
4. Scenario 4: This capacity is assumably 20% within the building.

3 RESULT AND DISCUSSION

3.1 Analysis of Questionnaire Results

The population within the Faculty of Engineering building included permanent and non-permanent agents, which contained men and women between 19-25, 26-40, and 41-60 years old (Figure 4). In this condition, data were also obtained from the Archive of University of Bengkulu (2021). At the peak time of 1 business hour, an interview was conducted based on the earthquake assumptions, with 250 respondents observed within the building. This population included 35%, 60%, and 5% permanent, non-permanent, and visiting agents, respectively. Using Solvin's solution (Equation 1), the sample quantities needed for the questionnaires were obtained, with distribution carried out based on the random selection of the respondents representing each room. This led to the interview of 71 respondents to explain the tendency of evacuation during earthquakes, with agents selecting the doors and stairs as exit modes being observed. These results were subsequently obtained from the dissemination of the conducted questionnaires.

Based on these results, the selection of the evacuation door as an exit mode is shown in Figures 6, 7, and 8. In Figures 6 and 7, the percentage of the selected evacuation exit was observed from the first and second floors, where door 1 (P1) was mostly picked due to being close to the assembly point. For P2 and P3, the obtained percentages were 3.9% and 12.99%, respectively, with P4 having the lowest selection based on being relatively narrow and located behind the stairs. This confirmed the general variations in the evacuation choices, as the agents represented their respective rooms during the questionnaire distribution. In Figure 6, most of agents on the second floor selected T1 to reach the exits, due to being the main stairs with larger evacuation space. Meanwhile, T3 had the lowest selected percentage due to only a few agents being close to the stairway.

The percentage results for each question are shown in Figure 8, where the data processing used the Likert Scale. This showed that the 1st, 2nd, 3rd, 4th, 5th, 6th, and 7th questions respectively explored the understanding of respondents based on the following (1) the earthquake disaster, (2) the safety of the building, (3) the building's evacuation route, (4) the position of the assembly points, (5) the building's early warning system, (6) the urgency of earthquake mitigation socialization, and (7) the urgency of evacuation signs. Based on the results, all respondents knew about the earthquake preparedness efforts, confirming that Faculty of Engineering agents had a basic understanding of the hazardous issues. However, they did not completely understand the early warning system, with half of them only believing in the essential need for socialization, to improve people's awareness of adequate disastrous evacuation. Agents also agreed that the safety aspect, evacuation route, and assembly point position should be appropriately understood.

3.2 ABM simulation results

The number of simulations is based on the sample size criteria suggested by Isaac and Michael (1995), which analysis with an error rate of 5% obtained 258 trials and observed the average value of each experiment. The Netlogo modelling was

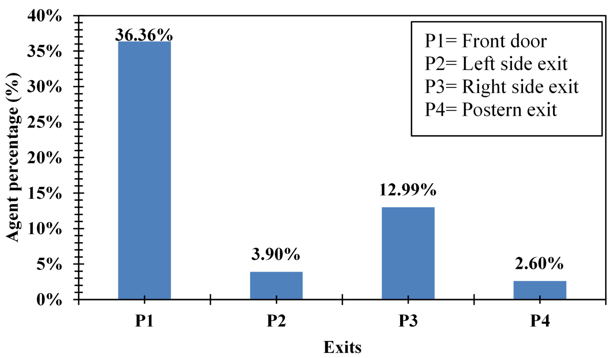


Figure 6 Percentage of agents on the first floor in selecting exit doors

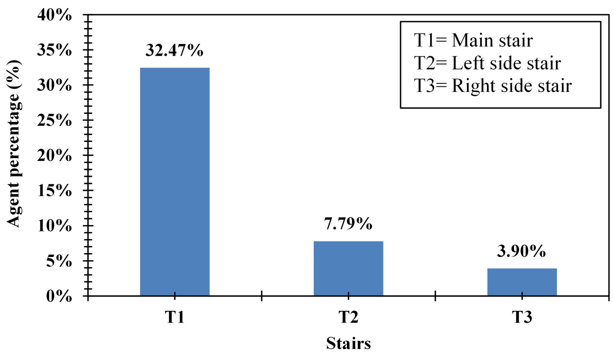


Figure 7 Percentage of agents on the second floor in selecting exit doors

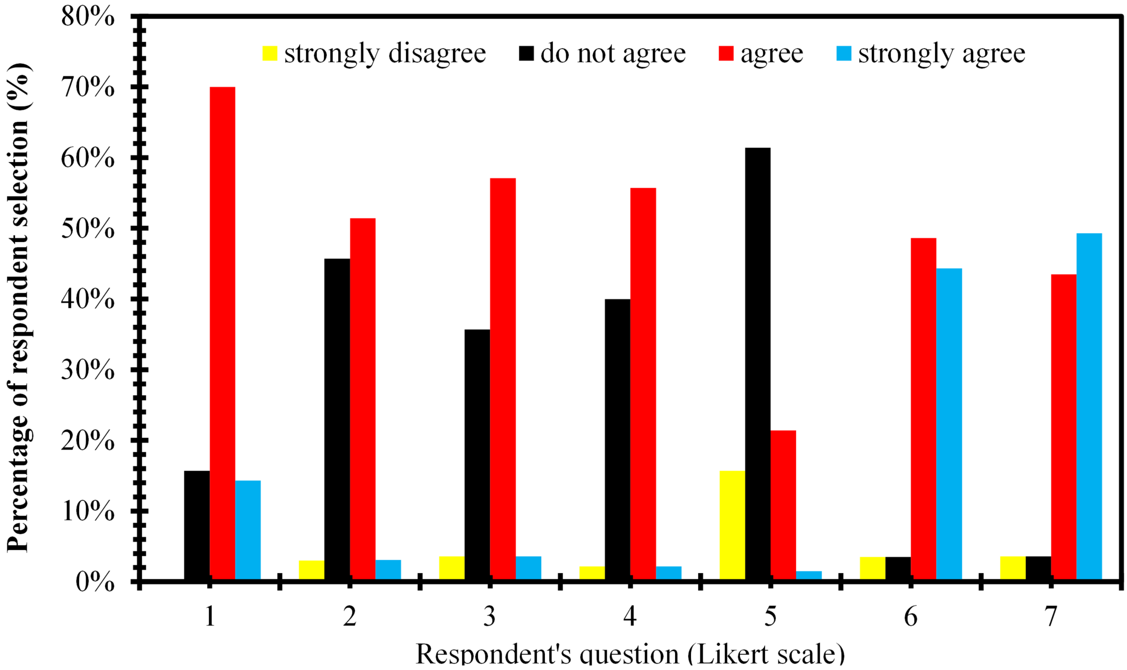


Figure 8 Likert chart (respondents' responses)

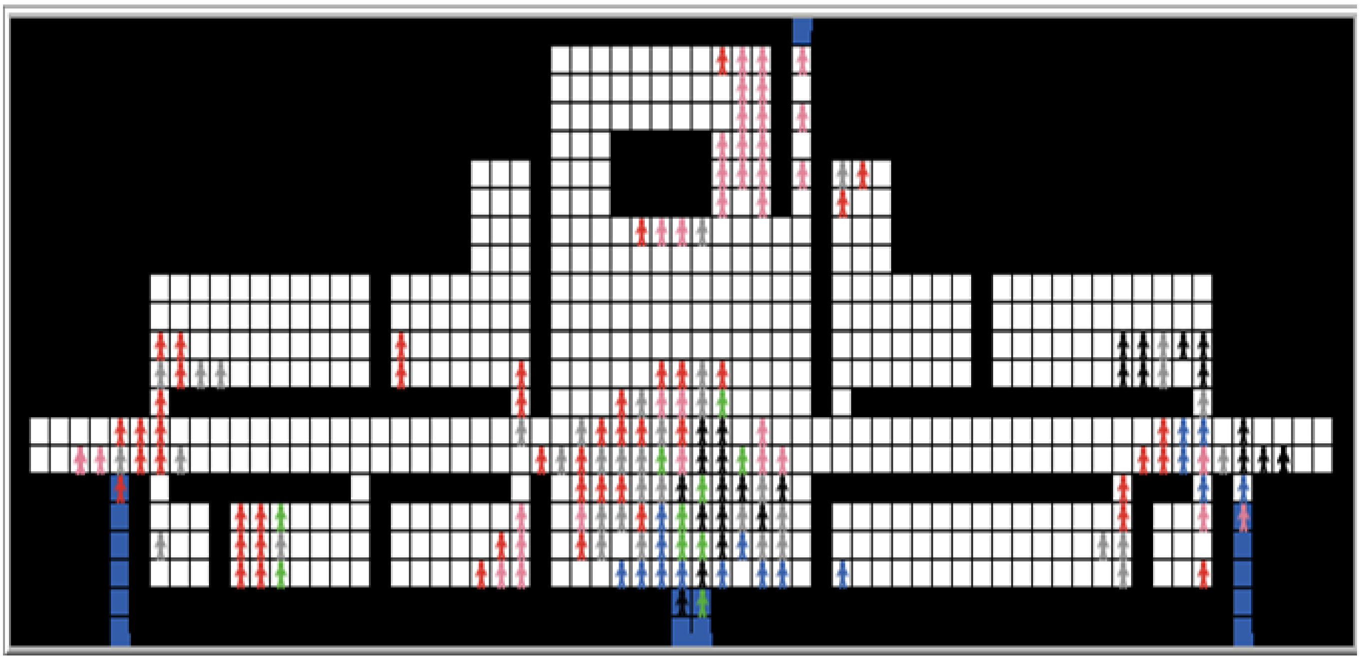


Figure 9 Density zones during the evacuation

also conducted to observe the comparison patterns between the existing (actual circumstances) and modelling conditions, using ABM. By observing agents' movement during the simulation (running), model validation was conducted when they exited the building, with errors acquired when the actual circumstances did not match the motion. These errors were observed by the incidence of agents trapped in the room. In addition, Figure 9 presents the density area that led to overcrowding during the evacuation, due to being generally found in all exits, i.e., P1, P2, and P3. It also confirmed that T1 underwent overcrowded condition, as the main stairway within the building. According to Figure 10, the performance of model results and realistic evacuation time were presented through linear regression analysis. Subsequently, this revealed the consistency between the simulation and realistic condition, where the validation graph obtained the determination coefficient (R^2)

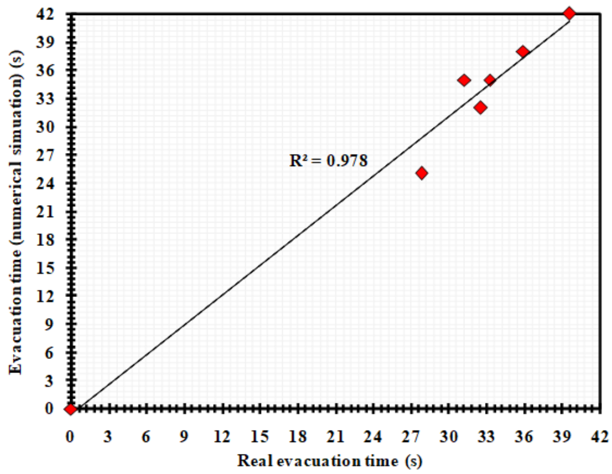


Figure 10 The performance of model results and real conditions for evacuation time

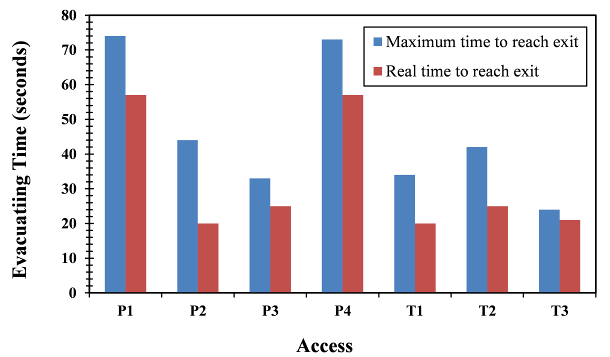


Figure 11 Modelling diagrams in agent-based modelling

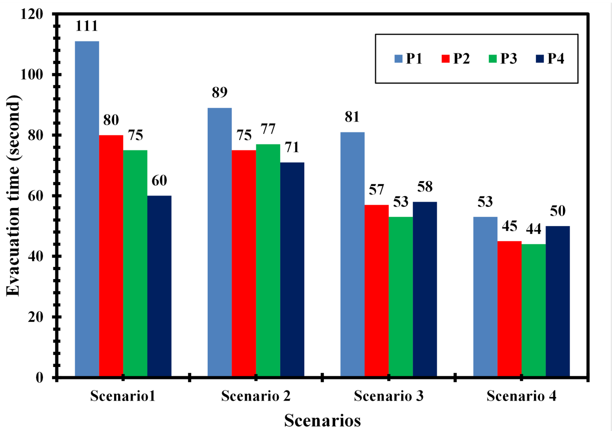


Figure 12 Comparison of each scenario

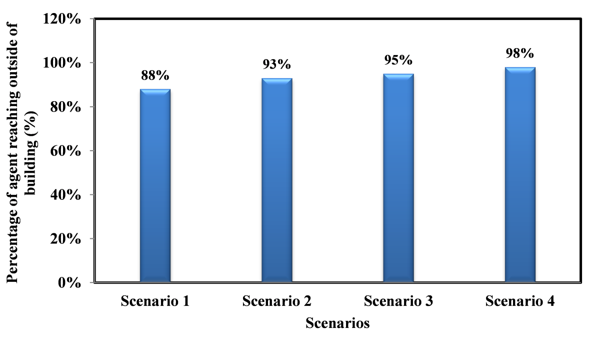


Figure 13 Percentage of the number of agents who passed the 1st floor of Faculty of Engineering building

of 0.978. This confirmed that the motion volume of simulation modelling had a similar tendency to actual circumstances. It also proved that the simulated and realistic conditions were generally consistent with each other. Therefore, ABM was used to simulate all the modelling scenarios.

For each scenario and the percentage of escaped agents, the comparison of the evacuation time is shown in Figures 12 and 13, respectively. In Figure 12, the longest and shortest evacuation periods to reach the exit were found at P1 and P4, respectively. Although the position of P1 was relatively far, most agents still preferred it as an exit route due to having a large gate. The selection of P4 for evacuation was not also highly observed due to its narrowness and opposite position to the main access. The volume of evacuation through this exit was nevertheless relatively small, leading to faster processes when selected by a few agents. Figure 13 also presents the percentage of agents that reached the assembly points during the evacuation, where Scenario 4 had the highest value due to only having 20% agent capacity within the building. This confirmed that the process of self-evacuation was quickly performed by agents, based on being relatively easy to reach the exit.

Figure 14 is a comparative analysis of escapees, influenced by the percentage of agents in the building. Using a ratio reading (AL/AT), the number of people who escaped the disaster was subsequently estimated, where AL and AT are successful and unsuccessful evacuated agents (%), respectively. This normal equation was carried out until closeness to the number of agents passing the ABM modelling results was achieved. Using the estimation equation of the developed model, the comparisons of the calculations are shown in Figure 15, where the observed value was relatively close to the simulated parameter. Therefore, the model

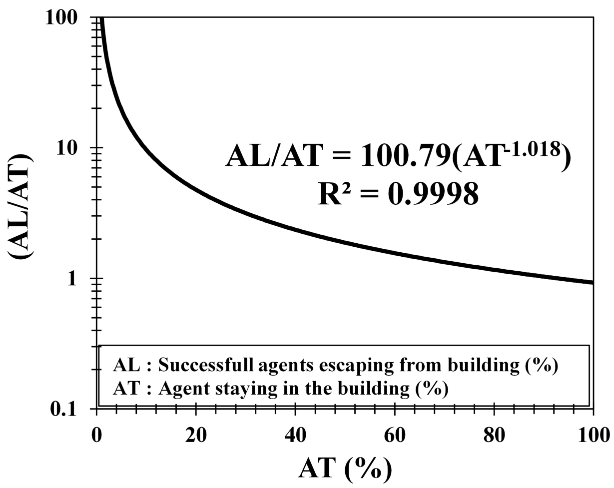


Figure 14 Comparison of the number of agents who graduated from Faculty of Engineering building

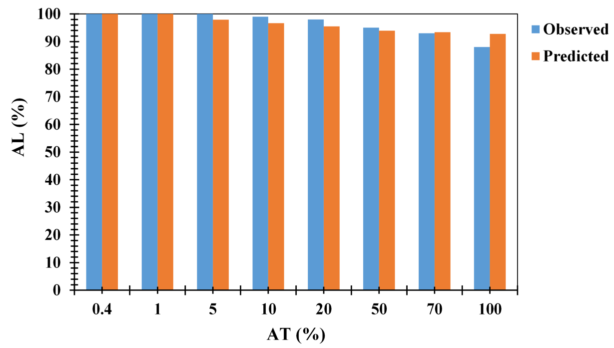


Figure 15 Comparison of the escaped agents' estimation

predicted the expectation of successful agents (escapees) from the building during evacuation.

4 CONCLUSIONS

This study aimed to analyze the implementation of Agent-Based Modelling, to observe the evacuating behaviours at Faculty of Engineering building, University of Bengkulu, Indonesia. The results showed agents' evacuation characteristics during the earthquake disaster. This revealed that the movement of the developed model was reviewed when the original position was occupied at the evacuation door and stairs, towards the assembly point. In the building, the scenario simulation modelling potentially displayed the conflict points hindering the evacuation process, based on the corridors on the 1st and 2nd floors, stairs (T1, T2, and T3), and exits (P1, P2, P3, P4). The travel time required to exit the building to the assembly point was also 111 s, with the agent population located inside the building's 100% capacity. Furthermore, the change in the travel period was influenced by the capacity of agents in the building, as a quicker evacuation period led to a decrease in the population of occupants. In this study, the proposed model also increased the knowledge to estimate the probability of evacuated agents (escapees) from the building. Based on the results, the empirical model was highly consistent with the simulation and prediction system. As the simple modelling for evacuation characteristics, the implementation of ABM is very important (Pratama et al., 2020; Nabila et al., 2020), as the presented framework in this study needs to be applied for subsequent cases in University of Bengkulu and other global problematic conditions.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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REFERENCES

Arai, R., Takahashi, T., Kodaira, S., Kaiho, Y., Nakanishi, A., Fujie, G., Nakamura, Y., Yamamoto, Y., Ishihara, Y., Miura, S. et al. (2016), 'Structure of the tsunamigenic plate boundary and low-frequency earthquakes in the southern ryukyu trench', *Nature Communications* **7**(1), 1–7.

Bonabeau, E. (2002), 'Agent-based modeling: Methods and techniques for simulating human systems', *Proceedings of the national academy of sciences* **99**(suppl 3), 7280–7287.

Cegielski, W. H. and Rogers, J. D. (2016), 'Rethinking the role of agent-based modeling in archaeology', *Journal of Anthropological Archaeology* **41**, 283–298.

Edara, P., Sharma, S. and McGhee, C. (2010), 'Development of a large-scale traffic simulation model for hurricane evacuation—methodology and lessons learned', *Natural hazards review* **11**(4), 127–139.

Farid, M. and Mase, L. Z. (2020), 'Implementation of seismic hazard mitigation on the basis of ground shear strain indicator for spatial plan of bengkulu city, indonesia', *GEOMATE Journal* **18**(69), 199–207.

Hardiansyah, Muthohar, I., Balijepalli, C., Priyanto, S. et al. (2020), 'Analysing vulnerability of road network and guiding evacuees to sheltered areas: Case study of mt merapi, central java, indonesia', *Case studies on transport policy* **8**(4), 1329–1340.

Hardiansyah, Priyanto, S., Muthohar, I. and Suparma, L. B. (2019), 'Identifying road network vulnerability during disaster case study: Road network evacuation in mount merapi eruption.', *Songklanakarin Journal of Science & Technology* **41**(4).

Helbing, D. (2012), Agent-based modeling, *in* 'Social self-organization', Springer, pp. 25–70.

Hinga, B. D. R. (2015), *Ring of Fire: An Encyclopedia of the Pacific Rim's Earthquakes, Tsunamis, and Volcanoes: An Encyclopedia of the Pacific Rim's Earthquakes, Tsunamis, and Volcanoes*, ABC-CLIO.

Isaac, S. and Michael, W. B. (1995), *Handbook in research and evaluation: A collection of principles, methods, and strategies useful in the planning, design, and evaluation of studies in education and the behavioral sciences*, Edits publishers.

Ishii, M., Shearer, P. M., Houston, H. and Vidale, J. E. (2005), 'Extent, duration and speed of the 2004 sumatra–andaman earthquake imaged by the hi-net array', *Nature* **435**(7044), 933–936.

Janssen, M. A. (2005), 'Agent-based modelling', *Modelling in ecological economics* **155**(1), 172–181.

Kasereka, S., Kasoro, N., Kyamakya, K., Goufo, E.-F. D., Chokki, A. P. and Yengo, M. V. (2018), 'Agent-based modelling and simulation for evacuation of people from a building in case of fire', *Procedia Computer Science* **130**, 10–17.

Lay, T., Kanamori, H., Ammon, C. J., Nettles, M., Ward, S. N., Aster, R. C., Beck, S. L., Bilek, S. L., Brudzinski, M. R., Butler, R. et al. (2005), 'The great sumatra-andaman earthquake of 26 december 2004', *Science* **308**(5725), 1127–1133.

Likert, R. (1932), 'A technique for the measurement of attitudes.', *Archives of psychology* .

Manandhar, B. (2016), 'Remittance and earthquake preparedness', *International Journal of Disaster Risk Reduction* **15**, 52–60.

Mase, L. Z. (2018), 'Reliability study of spectral acceleration designs against earthquakes in bengkulu city, indonesia', *International Journal of Technology* **9**(5).

Mase, L. Z. (2020), 'Seismic hazard vulnerability of bengkulu city, indonesia, based on deterministic seismic hazard analysis', *Geotechnical and Geological Engineering* **38**(5), 5433–5455.

Mase, L. Z. (2021), 'A note of ground motion interpretation and site response analysis during the 2007 bengkulu–mentawai earthquakes, indonesia', *Arabian Journal of Geosciences* **14**(2), 1–14.

Mase, L. Z., Sugianto, N. et al. (2021), 'Seismic hazard microzonation of bengkulu city, indonesia', *Geoenvironmental Disasters* **8**(1), 1–17.

Misliniyati, R., Mase, L., Syahbana, A. and Soebowo, E. (2018), Seismic hazard mitigation for bengkulu coastal area based on site class analysis, *in* 'IOP Conference Series: Earth and Environmental Science', Vol. 212, IOP Publishing, p. 012004.

Nabila, F., Mase, L. Z. et al. (2020), 'Numerical analysis using agent based modelling for tsunami hazard evacuation at building i, university of bengkulu, indonesia', *Potensi: Jurnal Sipil Politeknik* **22**(1), 21–32.

Norio, O., Ye, T., Kajitani, Y., Shi, P. and Tatano, H. (2011), 'The 2011 eastern japan great earthquake disaster: Overview and comments', *International Journal of Disaster Risk Science* **2**(1), 34–42.

Nur, A. M. (2010), 'Earthquake, tsunami and their mitigation', *Journal of Geography, Information Media, Geographical Development and Profession* **7**(1).

Pratama, D. P., Afrizal, Y., Mase, L. Z. et al. (2020), 'Implementation of agent based modelling method for tsunami hazard evacuation in building j, university of bengkulu, bengkulu, indonesia', *Potensi: Jurnal Sipil Politeknik* **22**(2), 114–122.

Proulx, G. (2001), Occupant behaviour and evacuation, *in* 'Proceedings of the 9th international fire protection symposium', Citeseer, pp. 219–232.

Putera, R. E., Nurasa, H. and Sugandi, Y. S. (2018), 'Synergizing stakeholders in reducing risk of earthquake and tsunami-disaster in the most vulnerable area', *BISNIS & BIROKRASI: Jurnal Ilmu Administrasi dan Organisasi* **23**(3).

Railsback, S. F. and Grimm, V. (2019), *Agent-based and individual-based modeling: a practical introduction*, Princeton university press.

Reyes, M. and Miura, F. (2016), A proposal for qualitative and quantitative analysis methods for vertical evacuation from a tsunami in coastal cities, *in* 'Coastal Management: Changing coast, changing climate, changing minds', ICE Publishing, pp. 97–107.

Richiardi, M. G. (2017), 'The future of agent-based modeling', *Eastern Economic Journal* **43**(2), 271–287.

Sahroli, A. and Hardiansyah, H. (2019), 'Analysis of tsunami disaster evacuation in the joint lecture building v, bengkulu university with abm method', *Inertia: Journal of Civil Engineering* **11**(2), 25–33.

Tumewu, T. W. (2017), 'Agent-based simulation for disaster evacuation of indoor field crowd gor x', *Widya Teknik* **15**(1), 41–45.

Wood, N., Jones, J., Schmidtlein, M., Schelling, J. and Frazier, T. (2016), 'Pedestrian flow-path modeling to support tsunami evacuation and disaster relief planning in the us pacific northwest', *International Journal of Disaster Risk Reduction* **18**, 41–55.