Department of Building, Civil, & Environmental Engineering

BIM-Integrated Agent-Based Modeling for Indoor Evacuation Behavior

Sina Bolandin (40057937)

Supervisor: Dr. Mazdak Nik-Bakht

Winter 2019

Contents

Abstract
Considering the new patterns of urbanization, particularly in metropolitans, individuals spend more time in buildings. Accordingly, in the event of a disaster, it is critical to ensure the safety of occupants during emergency egress. Emergency evacuation can be considered a socio-technical phenomenon; on the one hand, a plethora of static and dynamic physical components are involved in realization of safe exits during the disaster. On the other hand, human's behavior, controlled by a variety of physiological and psychological attributes impact the success of safe evacuation. Since actual experiments are not feasible, developing computational modeling is helpful to predict the occupants' behavior during evacuation. Static components of a building are normally modeled by Building Information Modeling (BIM) in the building digital models. Emergency planning, as a common BIM-use is meant to take advantage of such digital models to ensure the acceptability of a building design, from the point of view of occupants safety under disaster. In practice, however, this BIM-use has been limited to code compliance and controlling attributes of the static model. In this study we have tried to bridge the gap between BIM (as a digital and semantic model of the building's physical components) and Agent-Based Modeling (ABM) to model dynamic items like evacuees' reactions in a critical situation. While in the recent decades, several evacuation models have focused on fire evacuation; in this paper, the behavior of agents is assessed according to the egress National Building Code of Canada (NBC) to have a safe evacuation in any disaster circumstance. Then proposed model supports the micro level of detail including doors, windows, walls and main exit within NBC to simulate evacuation behavior in different scenarios. Width and length of building components and their layout, as well as the number of occupants, are effective factors on evacuation time. Our model integrates BIM geometry (retrieved from Revit) and ABM analysis via the open access engine NetLogo, to investigate the relationships between building layout in horizontal space and efficient evacuation. While some commercial tools exist for implementation of such simulations on BIM, our solution is meant to be open access and not vendor proprietary. The simulation model assesses the number of evacuees, panic behavior, congestion, occupant speed and evacuation time in different scenarios to monitor the effectiveness of NBC regulations.

Keywords: BIM, ABM, NetLogo, NBC, evacuation behavior, safe egress.

Chapter 1: Introduction

Considering the new pattern of metropolitan societies, individuals spend more time in buildings. Accordingly, in the time of the disaster, it is important to ensure the safety of occupants during emergency egress in indoor spaces. According to tentative data, the main reason for causalities in dozens of emergency evacuations from buildings is not the main disaster, however, the panic and impulsive behavior of crowd will be caused to increase casualties. Moreover, Numerous investigations depict that decision-making and finding the path increase the number of losses more than the disaster side effect. Ergo, the assessment of the effectiveness of individuals' behavior must be considered for evacuation study [1]. Computational modeling is a helpful toolkit to assess evacuation in the different scenario in a virtual environment. The model translates all human's behavior and physical components for prediction of individuals' panic behavior in a building [2]. Behavior is a phenomenon which is originated from various parameters such as age, gender, physical abilities, evacuees' speed, and past experiences. However, a bunch of behavior are fixed regardless of any specific case [3, 4].

Agent-Based Modeling (ABM) provides a platform to investigate evacuees' interaction in an emergency situation from a building [3]. Not only it has an ability to model navigation behavior but also it can model abruptive individuals' actions [5]. Therefore, the physical aspect of a building must be defined to simulate the agent's behavior a constrained space. Building Information Modeling (BIM) model the physical aspect of building.

In this study, it is focused on the evaluation of the architectural layout of a building. At the first step, the layout of the building is modeled in Revit as a Building Information Modeling tool. For simulation People's behavior, the geometry of the BIM model is imported in Agent-Based Modeling atmosphere to evaluate the egress building code of Canada in different alternatives. The individual is defined as an agent in this model. Agents' speed, panic behavior, and navigation modeled for each agent in different scenarios and situations. NetLogo as an ABM engine provides a 2D world to posit layout components same as imported geometry. Each agent has an individual and a group characteristic which impact on evacuation time. The number of fled agents and time of evacuation are compared in the different scenarios in order to achieve the results of the model.

Motivation and background

In spite of the fact that dozens of building are constructed based on building codes, they are not safe against disasters. Hence, the importance of evacuation planning will increase conspicuously. In order to define an evacuation planning, various evacuation scenarios must be considered which influence on the physical components of the building, however, they are controlled by building codes. Since evacuation planning should be considered as an effective asset beside building code, simulating evacuation behavior of people helps to assess all possible building layouts regardless of respecting building codes. In order to model static aspect of the building, there has been some effort to use Building Information Modeling (BIM) for indoor and outdoor modeling which are not adequate applicable to model evacuation behavior as the dynamic items.

To elevate the applicability of modeling and simulating, behavioral assessment tools must be used to monitor an evaluate the layouts of buildings based on humans' features. Considering the demands of evacuation planning beside building code, this report will provide a model to bridge the gap between static and dynamic items of the building via BIM and ABM engines.

Problem statement

Although dozens of buildings are constructed based on the national building code of Canada, we have been witnessing numerous casualties in different disasters. Obviously, the building code provides the magnitude or intensity that must be exceeded, and the layout of buildings are controlled according to national building codes to meet the threshold of measurements. Thus, the demand to assess the evacuation plan of the building is essential which is not feasible to investigate as a real circumstance owing to enormous costs and casualties. Loads of researches have done to assess the effect of fire for emergency evacuation. However, fire is a common critical circumstance in buildings, the demands to assess evacuation time and users' behavior for any type of disaster is valid.

Design is a multi-disciplinary subject which is not limited to physical aspects of building. Building information modeling as a design tool has an ability to model static components of building in various scenario however, users' behavior should be considered to have a safe design specifically during a disaster.

In this report, the effects of floor design on the evacuation time are monitored. To have a more realistic simulation, the panic reactions and individuals' speed is modeled.

The goal of the study

The main goal of the project is:

Assessment the role of building components and human's behavior on evacuation time.

Following objectives are on the track of this goal:

- ❑ The integration of BIM and ABM engines to simulate the interaction between occupants and physical components of the building layout.

- ❑ To assess the sensitivity of evacuation time to social and physical aspects of building design.

Chapter 2: Literature Review

Respecting to recent researches, a plethora of evacuation models have been developed to assess the behavior of evacuees and time of evacuation [6]. The evacuation models are used to estimate the effect of fast flows of evacuees and interaction amongst individuals during emergency exit [7].

Monitoring people's behavior in emergency evacuation has been done in both experimental and simulation surveys to exit in different scenario. For instance, Helbing et al. (2003) assessed the students' evacuation from a class, which was resulted the jamming of the students has influence on the evacuation time. In addition, Shi et al. (2015) did a survey in laboratory situation, to examine the safety of individuals that reveals the merging angles have a significant effect on pedestrians during the emergency evacuation [7].

Additionally, choosing exit door, during emergency evacuation has been studied. For example, choosing the exits happens haphazardly, which is affected from uncertain behavior of evacuees. This selection is influenced by the amount of familiarity with exits [7, 8]. It is obvious; people opt to choose the exits that are nearest. Moreover, the width influence to choose exits during evacuation. Factors such as light above exits, green flashlight and guide are effective elements on evacuation time. Fue et al., 2016 did a study on a pedestrian evacuation, which employed a simulation model from a single room. Results depicted that elements, such blocking exit, unorganized outflow and arching were seen at evacuation time. It is predictable the crowd follow other persons in emergency. [3, 9]

Evacuation modeling has been done according to different models of simulation. The study, which has been modeled by using the social-force model, demonstrates that increasing desired evacuees' speed causes increasing evacuation time. This survey did with different door sizes and the more the door size increases, the more the influence of desired speed decreases. Another simulation in this study as a one floor with two rooms and one main exit and hallway, shows that decreasing room door size improves evacuation efficiency in certain emergency. Because the room doors decrease the crowd in hallway causing smaller density in the main exit. In multi-room floor and buildings, the main factor of evacuation time is the exit size. The main exit door of a building has a significant role in evacuation time in comparison, the interior door of building. [3] Furthermore, the availability of more exit door is related to decreasing evacuation time [7].

Qing Xiong et al., 2017, with applying geographic information system (GIS) and architectural modeling from micro level of room and individual and macro level of multi-story building model assessed the relation between location of exits and the probability of congestion in each exit door. In their models, all exits had same geometric size and they located in different location [1, 9].

Faroqi & Mesgari, 2015 [6], simulated the behavior of individuals with a multi agent-based modeling in NetLogo atmosphere. They considered three exit doors and six emotional reactions for adult, children and security. In that model, agents find the exit and then they help other agents.

Inside navigation to exit is challengeable factor. Limitation of walking speed, uncertainty of paths, corridors and stairs, and inaccessibility of elevators decrease the speed of inside navigation especially in multi-story buildings. Extinguishing fire and rescuing process to remove people are not succeeded from outdoor of building and are time consuming. Hence, inside strategy to decrease causalities must be considered [10]. Inside evacuation strategy needs accurate information from inside buildings as number of people in different hours of day, constrains, paths and exits that facilitate simulating evacuation behavior. These physical and semantic information must insert in simulated model. There are various advantages for simulating a model [11]:

- The whole or part of project can be assessed and debugged without the demand to experience in the real world.
- Different scenario, optimistic, pessimistic and most likely can be tested easily in a simulated project.
- The model can be repeated several times to understand bugs of real project.
- Time consuming in comparison with real check and control.
- Obtained data can be used for educational and research purposes.

It has been witnessing different evacuees' behavior during evacuation process. These behaviors are categorized in three levels: 1) each person, 2) between persons, 3) group behavior. These behaviors are originated from the knowledge of people from the closed space. Additionally, they have influence on the speed of exit. In simulating space, all these behaviors should be defined to have an accurate simulation. An army of researches indicate that the number of casualties increases owing to lack of making appropriate decision-making and navigating during evacuating [1].

Each person

Each person's behavior is rooted in psychological and spiritual situation of agent in an emergency situation. This situation must be considered on the result of individual's decision- making. It is assumed that an individual's behavior is affected by instinct, last experience and bounded rationality [12]. In emergency, there is a demand to make a quick decision to find optimal solution under following instinct. Fear, pushing other people breaking windows and running toward exits are reactions which are based on instinct [12, 13]. This element has significant effect on finding path. Experience is another factor which has influence on the people's reactions. An amount of familiarity of people with the space and image of the space will help them to reaction more rational. According to last researches in an emergency situation, people tend to familiar exits. Moreover, reactions in emergency circumstance are similar, thus, people follow a bunch of similar activities, however, individual's experience in similar situation is not effective to increase the chance of appropriate decision making [12, 6, 13].

Rational item considers consequences of each alternative for decision –making. This process includes searching to find possible options, anticipating consequence of each alternative, weighting alternatives and finally choosing of making decision according to consequences. Generally, the result of rational attitude is more reasonable than experience and instinct [12, 6].

To sum up, in evacuation situation four activities will happen. 1) Observation means people collect information from surrounding. 2) Decision- making, in this activity, as an immediate action, people find nearest exit door. 3) Navigations are middle targets to reduce the path toward final exit. 4) Movement that is a step to pass physical constrains [13]. All these activities are originated in human's instinct. It is an asset to assess the individuals' behavior during simulation for increasing the accuracy of simulation.

Interactions between persons and group behavior

After considering the individual's behavior, the group behavior must be anticipated for assessing crowd. Although the group involves combining individuals, interaction among evacuees increase or decrease the speed of evacuation. Moreover, this is a fact that the feeling of each agent such as fear and stress in a critical situation, extend amongst other agents. As mentioned Xiaoshan Pan, [12] group behavior is included: social identity, personal space, and social proof.

Social identity: according to observations, a group of people has different behavior in comparison with each person's behavior. Generally, in a critical situation, the crowd will face a danger which is enforced people to evacuate from egress. Each person in a group has a background which is rooted in the structure of society that he/she is being. Rules, regulations, culture, religion, duties, and jobs are effective factors on group interactions [12].

Personal spaces: individuals have a specific boundary around them to define the border to interact with others. This border is different in different culture and society. As the truth or facts of an emergency situation, this border will change, and people enter in boundaries of others and they accept others' entrance. Additionally, fear, stress has influence on the acceptance of others' right in egress which are caused aggregation [12, 14].

Social proof: when people deal with critical situation which they do not have adequate information, they prefer following others blindly. Sometimes this behavior helps them to exit sooner or may have reverse result. Moreover, dozens of people do not react as a first person, but they wait to other reactors. As soon as first reaction from person, others may follow or not his/her behavior [12, 14].

As a matter of fact, the result of evacuation depends on evacuees' behavior. As mentioned, individual and group behavior of people are affected from different factors, in addition, the degree of uncertainty and outside risk. Modeling with considering feelings and interactions amongst individuals increase the accuracy of simulation [14].

Monitoring occupants' behavior

There is various methodology for monitoring and predicting agent's behavior. There are three significant models: Macroscopic models, Microscopic models and Hybrid models. Macroscopic models are nominated to similar behavior such as traffic density for example fluid dynamics models. Macroscopic models are according to agent's behavior such as cellular automata, lattice gas, social force, agent-based, game theory and experiments with animals**.** Hybrid models are a combination of microscopic and macroscopic [12, 15].

Table 1: Summary the merits and demerits of models used in crowd simulation [15, 1, 6]

Models	Description	Merits	Demerits	Publications
Cellular automata	The value of each cell depends on the value at the neighbor cell. This model combines with other models for evacuation experiments.	(1) Be suited for largescale in simulations. (2) Represent many collective behavior. (3) Describe some phenomena during crowd evacuations.	(1) Cannot properly consider high-pressure characteristics. (2) Ignored some prominent effects such as falling, injury etc.	[Reggia 1998, Zheng 2011, Pelechano 2008]
Lattice gas	This model is same as cellular automata, but each cell can have independent value from its neighbor.	(1) Be suited for largescale in simulations. (2) Represent many collective behaviors. (3) Describe some phenomena during crowd evacuations.	(1) Cannot properly consider high-pressure characteristics. (2) Ignored some prominent effects such as falling, injury etc.	[Zheng 2009, Tajima 2001b, Tajima 2001a, Tajima 2002]
Social force	The movement of each pedestrian depends on destination, distance from others, distance from obstacles such as walls and attraction by others. On the other hand, the interactions amongst pedestrians depends on enforcement from neighbors.	(1) Simulate the most typical phenomena observed in pedestrian dynamics. (2) Achieve very realistic simulation results. (3) Reproduce some observed behavior of pedestrian flow.	(1) Assumptions oversimplified. (2) Consist mainly of three terms corresponding to the acceleration (3) Cannot consider perceptions of individuals and local decisions.	[Helbing 1993, Helbing 2002, Song 2013a, Duives 2013, Parisi 2009, Wei-Guo 2006]
Fluid-dynamics	This model defines group behavior as a fluid going and does not consider the detail behavior of each pedestrian. Average	(1) Represented nonlinear partial differential equations. (2) Satisfy unsteady situations.	(1) Not detail (2) Highly non-linear and set up based on several hypotheses. (3) Not flexible.	[Al-nasur 2006, Smith 2009, Singh 2009, Lu 2008, Jin 2012,

Models	Description	Merits	Demerits	Publications
	characteristic and speed are assessed.		(4) Limited value except at dangerously high crowd densities.	Luh 2012, Parisi 2009, Duives 2013, Ha 2012]
Agent-based	In agent-based modeling (ABM) has an ability to define individual and group behavior with personal and collective goals.	(1) Capture emergent phenomena, (2) Provide a natural description of a system (3) Be flexible (4) Describe successfully pedestrian behavior.	(1) The task to model human agents' behavior is difficult. (2) Cognitive models are highly sophisticated. (3) Require large computation.	[Zhang 2009, Shendarkar 2008, Qiu 2010, Navarro 2011, Song 2013b]
Game theory	It is a mathematical model theory which tries to predict and simulate relationship between occupants and optimal decision.	(1) Be ideally suited to analysis of human reasoning and strategic thinking in an evacuation.	(1) The outcome of a game is characterized by a payoff matrix. (2) It is difficult to identify the large number of "players".	[Lo 2006, Lachapelle 2011, Zheng Xiaoping 2009
Experiments with animals	A bunch of researches concerned the group behavior of animals such as ants and mice for group modeling of human.	(1) Realistic crowd evacuation behavior can be understood easily such as escaping behavior of mice and ants.	(1) Human beings are greatly different from mice and ants in experiments	[Klingsch 2010, Helbing 2003, Calvez 2007

Agent based modeling

Computational model follows an algorithm to simulate the actions and performance of a system. This process enhances the simulation models to be more realistic. Surprisingly, adaptive feature of ABM to broaden the ability of agents to interact with their surrounding more reality is a fact to use ABM as a simulating technique in comparison others. [16, 17]

Rand 2006 explained this feature for ABM as a machine learning technique. As a simple view, agent-based model includes three steps:

1) Specify the world and number of agents,
2) Agents observe their world,
3) Agents act and decide as their observations,

And the model rounds this cycle to the end. Respecting to the ML, there is a step between 2) and 3), agent adapts its behavior with environments as shown in Figure 1 [16].

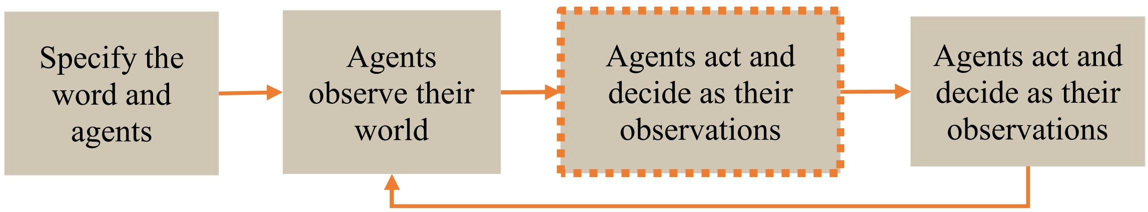


Figure 1: Adaptive quality of AMB as a ML technique can insert between step 2 and 3 [16].

ML technique increase the ability of AMB to provoke agent to be smarter as a human's behavior.

Human's behavior is significant factor in the result of evacuation. During this process, individuals make decision to find optimal path. Finding shortest way, choosing the exit, moving in corridor are affected by the individuals' behavior. Moreover, human emotion such as fear, stress, panic, etc. is another factor which causes nonadoptive crowd behavior [4, 8]. Eric Anderson et al. indicated, that behavior like pushing and trampling as destructive behavior which happens in emergency [4]. All signs and trainings have a goal to decrease the destructive behavior for making optimal decision in emergency circumstance.

Studying human's evacuation behavior is complicated, because not only various physical features have influence but also, psychological aspect should not be neglected. As mentioned in table1, many methods have been using to increase accuracy of computational assessment. Agent-based modeling (ABM) is a computational tool for simulating humans' behavior. The atmosphere of ABM defines artificial space like building to disperse agents in different rooms and divided space. Agents has an ability to interact with each other and they can have autonomous characteristic. This feature increase reality of simulation and accuracy of results [4], this feature of ABM helps to simulate psychological characteristics of agents.

ABM provides a platform for modelling/simulation of complex adaptive systems by defining agents' behavior in a graphical manner for assessment several designed scenarios. The output of simulation is useful to monitor the system's behavior in prototype environment. Conspicuously, these tools provide a powerful simulation atmosphere which have an ability fast testing. There are several visualization technologies behind ABM platforms. A bunch of them use 2D graphics while others use 3D graphics. The visualization quality helps to indicate the actions of agents more realistic. Moreover, it can be experimented blurring and resizing multiple agents in different situations [3, 18].

Agent-based modeling is based on behavior and making decision [19, 15]and these two items are ability of ABM for simulating. Simulation of behavior divides two factors: objectively and subjectively. Objective factors include physical aspects of building and circumstance, number of crowd and Subjective factors include features of individuals such as age, health, response and move ability. How to apply and reflect these features in the model is the art of simulating. In some agent-based models, agents take the role of humans. This participatory of agents is helpful in order to educate people for emergence or critical circumstance. Besides, it is useful to test and verify the rules and conventional emergent behavior [5, 20].

To sum up, ABM engines have beneficial and constructive effects on simulating. The main benefit of ABM over traditional variable-based modelling is that simplifications do not must be created to form the model mathematisable or feasible utilizing a lot of mathematical calculations. However, the ability of ABM relies on its ability to accurately and falsifiability justify and model the complexness of real-world interactions [20].

NetLogo as a toolkit for ABM simulation

Various platforms have been enhanced to aim ABM modeling. NetLogo platform is the Logo family of agent-based modeling which has its own programming language and a set of libraries. Some other ABM engines such as Swarm and Mason have a set of libraries programming and a few rules for constructing a model however, the Logo programming is simpler than Java or Objective-C. Its programming language contains many high-level and primary structures which enormously decrease programming effort [5]. There is a misconception about NetLogo that because of own programming language and simple atmosphere, there is a limitation for sophisticated ABM analysis. Steven F. Railsback et al., compared different platforms of AMB and they could carry out all ABM modeling in NetLogo with less effort than other ABM platforms [18, 21]**.** Furthermore, NetLogo has been intelligibly designed with a specific type of model of mind[1]: mobile agents acting simultaneously on a grid space with behavior interactions [18]. The graphical interface of NetLogo provides a space to run ABM model and this feature is one of the significant benefits of NetLogo in comparison with others ABM software like RePast and Swarm [20].

The 2D or 3D view of NetLogo depicts any modeling which is supported by logo programming in code space. The interface is included square patches as static component and turtles as agents to interact in simulated model [20].

Another specific feature of NetLogo is that it represents coordinate of agents and navigates them to specific location of X and Y coordinates. In the other ABM engines, agents must be departure from the locations, then set in the new locations and end up updating the agents' coordinates [18].

In this manner by and large, it tends to be progressively useful to monitor agents' behavior from start-point to end-point in evacuation scenarios.

[1]) model of mind or theory of mind is phrase in psychological science which refers to whatever we believe, and act are influenced by how others believe or act. ABM as a simulation engine has an ability to implement computational modeling the interaction among people as an interaction among agents [24].

Last but not the least, while a bunch of commercial tools exist for performing of simulations on BIM such as Pathfinder software, NetLogo is an open access and web-based program which can be used as a SaaS2 which allows users to connect the internet and use cloud-based applications.

[2]) Software as a Service

Chapter 3: Methodology

More and more, modeling evacuation behavior is going to be an element of evaluation building-safety. Occasionally, engineers use mathematical tools to calculate emergency movement especially from main exit. To gain realistic evacuation simulation, engineers have been trying computational models to assess the building layouts. Behavioral models contain decision- making by occupants due to the critical circumstance in building. In second step, humans move from their location to the exit [22]. Erica D. Kuligowski et al., 2005 determined modeling methods in 3 main categories: Behavioral models, Movement models, Partial behavior models. According to these categories shows the purpose of simulation model as a users' chosen or building chosen. After defining the purpose of modeling, other factors such as the complexity of egress, 2D or 3D modeling, the platform of simulating and availability to the public. As a matter of fact, these features are as an ID for any evacuation modeling [22].

As shown in Figure 2, various psychological and rational factors have influence on models. Some elements such as building components are static items whereas, louds of items depend on people's attitude in critical situation.

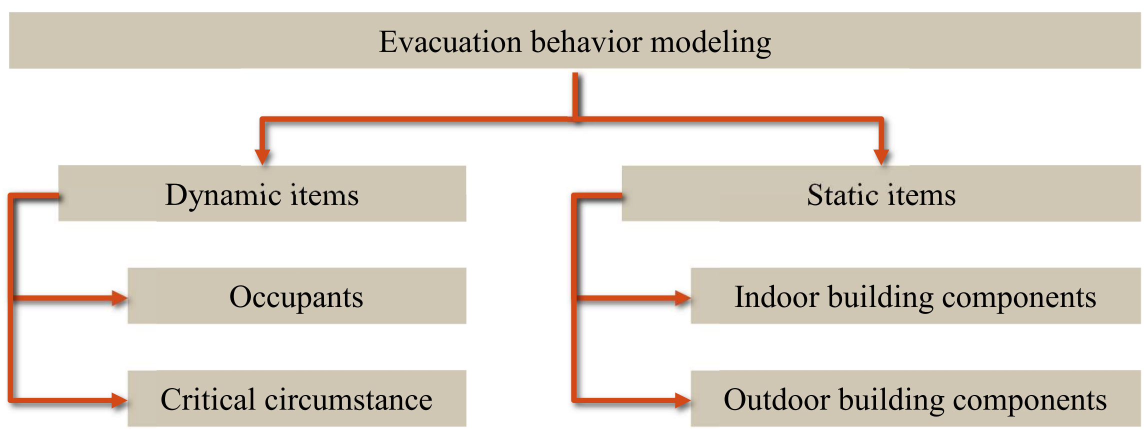


Figure 2: Static and dynamic items in each critical circumstance

- Occupants:

Age, gender, culture and physical condition are prominent factors in concern of modeling occupants' behavior. Generally, all occupants of a building do not have enough information about building emergency exits, corridors and access doors especially in commercial buildings. Although, national building code has determined rules for signs and color of exit (sortie), it is obvious, daily clients to office and commercial buildings do not considers to all signs. As mentioned, stress, fear and haphazard manners cause congestion in emergency.

- Critical circumstance:

Each evacuation happens due to a circumstance such as fire, earthquake, terrorist attack, etc. however, in entire events, occupants try to find optimal path. Thus, decision as an individual or group will make.

- Indoor building components:

Indoor components including fixed and non-fixed items affect the path finding and evacuees' speed directly and indirectly. Walls constrain the movement of occupants from rooms to corridors and room doors and unit door are main exits to evacuate from each unit building. Furniture in each room reduce the speed during evacuation. Hence, the location of fixed and non-fixed components influences over the evacuation time and number of casualties.

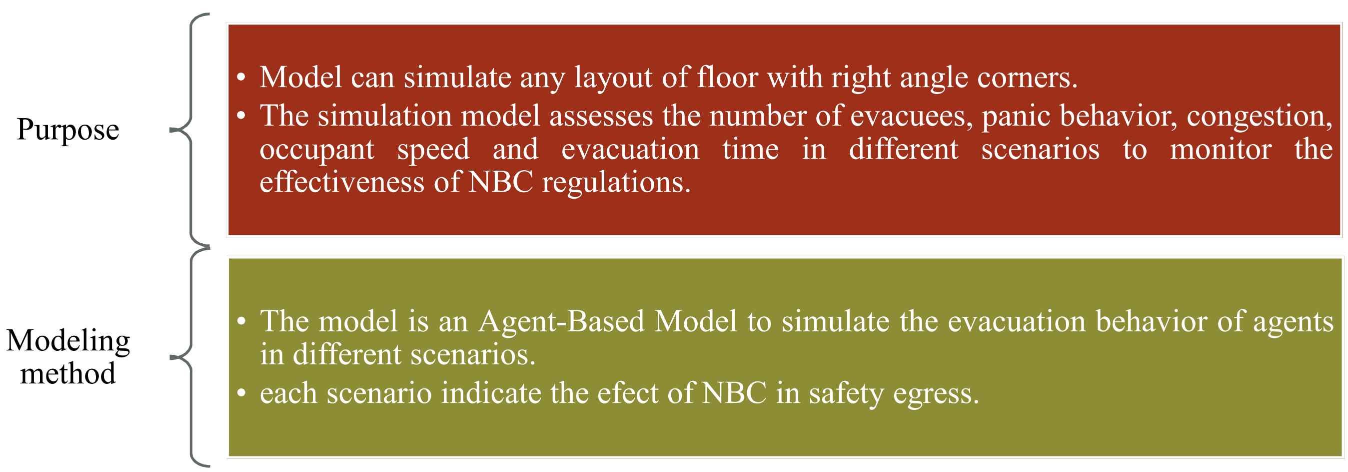
- Outdoor building components:

Outside building unit corridors, stairs and elevators are elements to follow crowd. Making decision to choosing and number of floors are effective factors in evacuation.

The specification of the proposed model is presented below.

Proposed evacuation model
According to the Figure2, static and dynamic items of a critical circumstance must be modeled. Generally, in ACE projects, static items are built by Building Information Modeling (BIM). Moreover, dynamic items such as the individuals' behavior during circumstance are modeled to imagine the real situation in a computational space. As mentioned before, ABM is a powerful engine to simulate human's reactions**.**

Thus, the model defines the agent's behavior in a simple plan, and it will be followed the speed and panic agents' behavior to monitor building codes inside of a building like, door size for exit and room, room dividers such as walls and some furniture. Respecting to model categories which have been done by Erica D. Kuligowski et al. the features of proposed model is depicted in Figure 3.



Structure of model

- proposed model supports the micro level of detail including doors, windows, walls and main exit within NBC to simulate evacuation behavior in different scenarios.
- The layout includes 4 rooms with different functions:
  - room-1: as a office space with considering occupants loads for an work place.
  - Room-2: Management room: as a space for limited number of people.
  - Room-3: Meeting room: a space for presentations.
  - room-4: Cafeteria: a space for drinking coffee, eating lunch.

Behavior

- In this model, agents are navigated from their locations to main exit. The panic behavior and abruptive reactins are modeled as changing speed and transfering fear to other agents.
- Each agent has an initial fear (In NetLogo model, it has been set by a slider the number of scared from 0 to the number of occupants).
- The initial fear can be transfered to other agents (In NetLogo model, it has been set by a slider the percentage of transfering scared)

Movement

- Agents scatter in layout in 4 different rooms randomly, then they flee to exit door of each room and main exit.
- The movement of this model starts from any point of floor layout to main exit.
- The main challenges of agents' movement is congestion.

Circumstance

- Any unpredictable events can be considered in this model such as fire, earthquake. trorist attack, etc.

Availibity to public

- The model integrates BIM geometry (retrieved from Revit) and ABM analysis via the open access engine NetLogo, to investigate the relationships between building layout in horizontal space and efficient evacuation.
- While some commercial tools exist for implementation of such simulations on BIM, our solution is meant to be open access and not vendor proprietary.
- The result of the model can be extend to any layout of floor for assessing the egress according to NBC.

Figure 3: Respecting to model categories which have been done by Erica D. Kuligowski et al. the features of proposed model is depicted

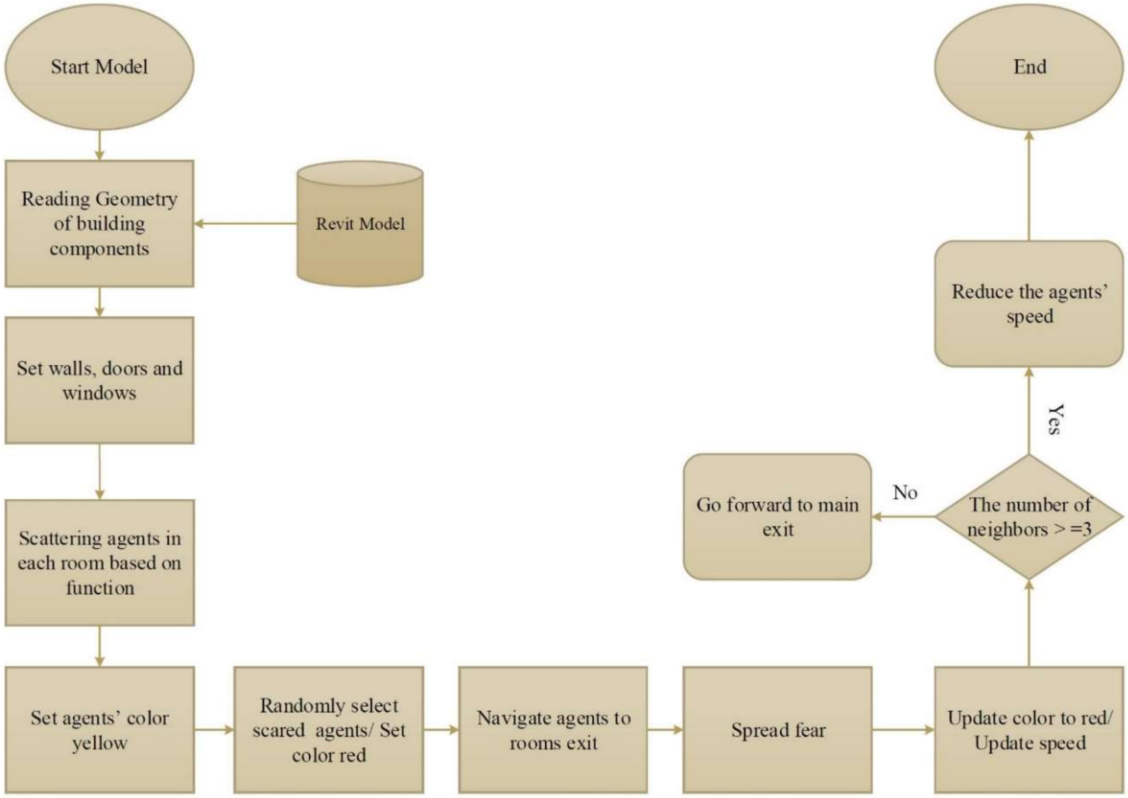


Figure 4: The whole process of bridging between BIM model and ABM simulation

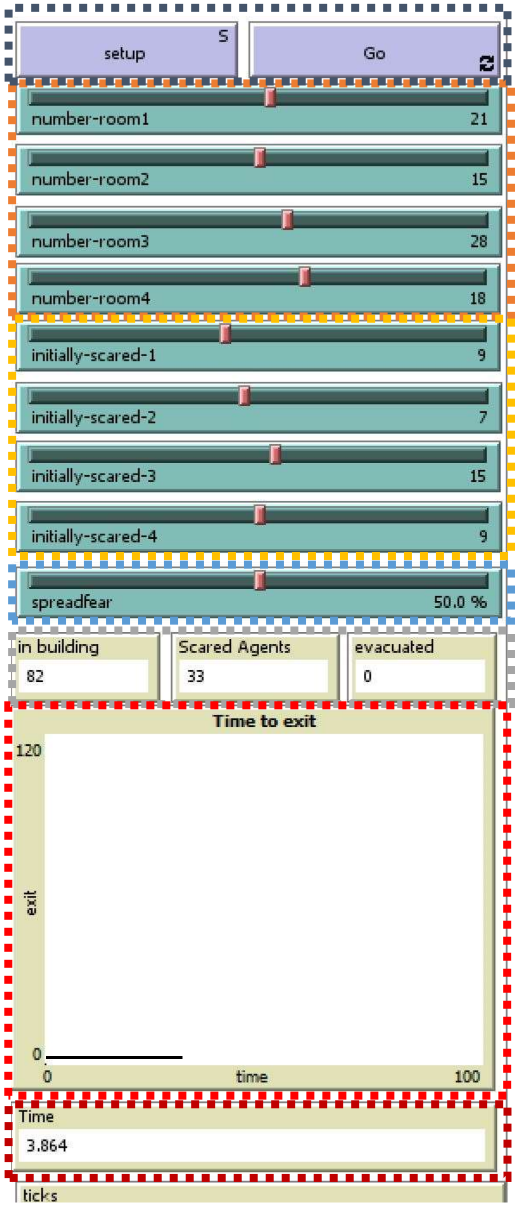


Figure 5: The NetLogo model for simulating model

The buttons setup the model and run the simulation.

As a slider defines the number of agents in each room.

As a slider defines the number of agents with initial scare.

As a slider defines the percentage of spreading fear to neighbours of each agent.

The monitor shows the number of agents in building, the number of scared agents and evacuated agents.

The chart shows the time of evacuation base on the number of ticks.

The chart shows the time of evacuation base on the real time (sec).

Chapter 4: Case Study

As mentioned, the model deals with static and dynamic items to simulate the disaster scenarios. BIM and ABM are powerful tools to provide appropriate space for modeling. In following the process of modeling static and dynamic items have described.

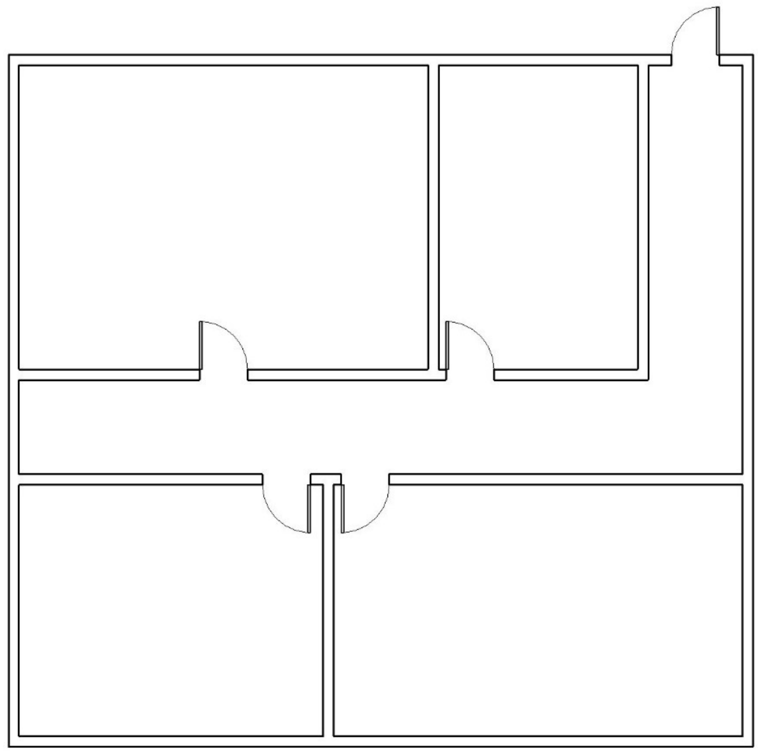


Figure 6: The sample layout of model for simulating

Static items: Physical elements of model have built by BIM. Revit as a software of BIM package helps to draw physical components of building. The project has focused on main physical components of building to determine accessibility and inaccessibility to space regardless of furniture which are included walls, windows and doors in any layout of building. Moreover, this study has tried to assess the egress code of NBC and extend the results to any building. As mentioned in structure of model, the layout of model has 4 rooms and one corridor to join the rooms to gather. Figure 6 shows the simple layout of model.

In order to build a meaningful model of evacuation as human movement, the model must be able to represent both the current location of the persons, as well as the action or behavior which they exhibit as a result of this state. ABM provides a space for satisfying these conditions.

For bridging between BIM model and ABM engine, the Revit model should be imported in NetLogo interface for simulating occupants' behavior. Therefore, the Geometry of building components must be exported from Revit model. There are two tools to read the geometry of building components in Revit software, Dynamo and Revit API.

Dynamo is a user-friendly programming that has an ability to create your own nodes, use Python, and download Packages. In addition, Dynamo is a visual programming language which provides an environment for programming for the BIM software Autodesk Revit without any prior experience. Whereas for working with Revit API, it is essential to know how to code with C#, VB and Python programming and to have the knowledge the logic of coding. For exporting the geometry of building component, the Dynamo tool has been chosen. Dynamo as an add-in of Revit reads the geometry of components, then they are exported as a XLSX format. Figure 7 shows the process in the Dynamo interface for reading the Geometry.

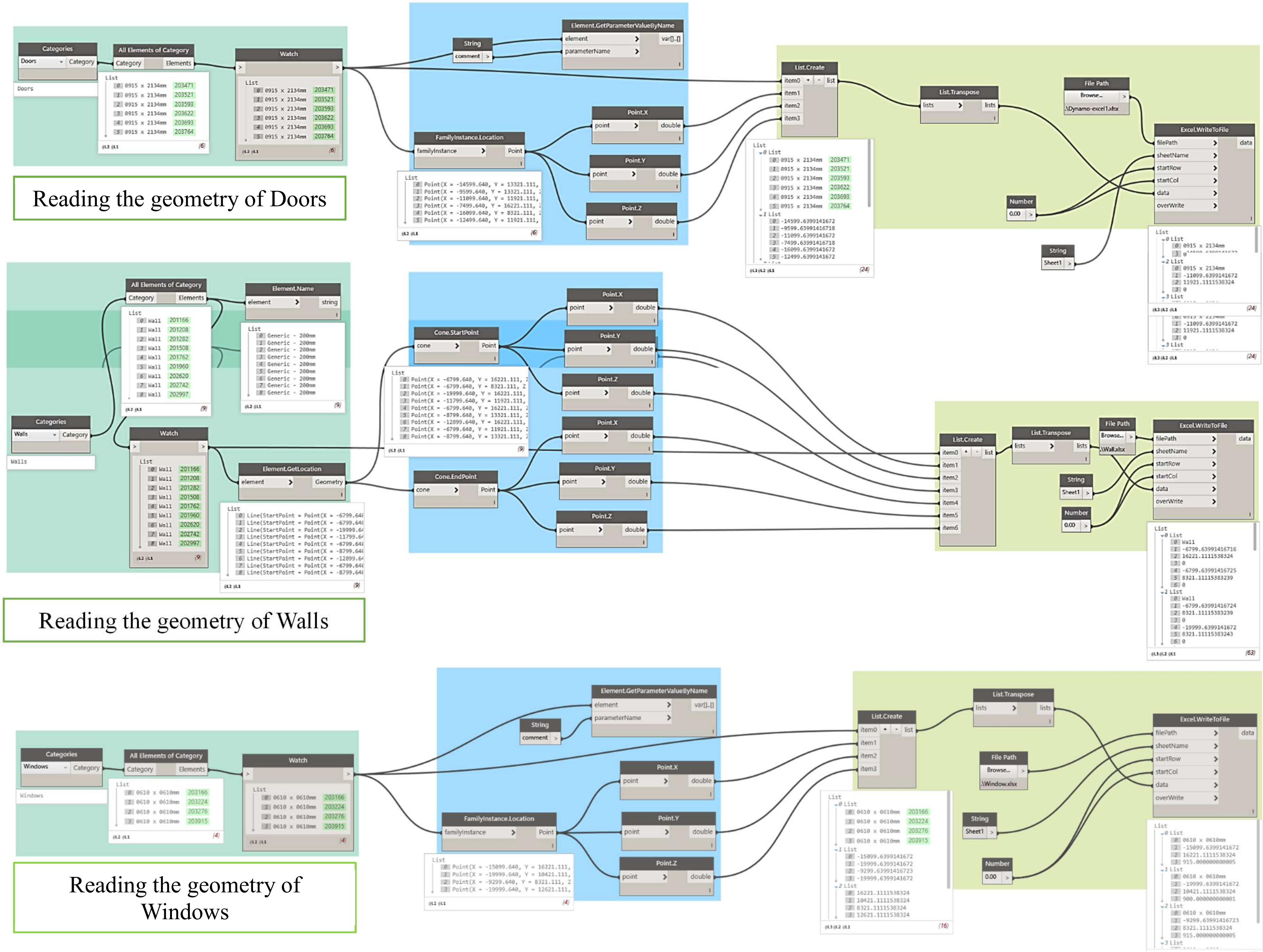


Figure 7: The Dynamo process to export the geometry of components

Set the layout in the ABM engine (NetLogo)

In the next step, the geometry of building components must be inserted in NetLogo interface to define the space. It means that the location of walls and doors must be determined according to the geometry of start and end point of each of them. The chart below shows the process of exporting the geometry from Revit model and importing them in NetLogo.

1) Export the geometry (X, Y) of start and end point of building components as a XLSX format via Dynamo

2) Change the XLSX format to CSV format via Microsoft EXCEL

3) Change the XLSX format to CSV format via Microsoft EXCEL

4) Prepare the geometry data for coding in NetLogo (This step would be explained separately)

5) Import the geometry in observer space of NetLogo

6) Define elements in code space with copy and paste geometries

Figure 8: The Process of importing geometry of components in NetLogo

Step 4 is the challenging step of this process owing to the simulating interface of NetLogo has a limited space thus, the scale of layout for importing in NetLogo must be changed to a readable size. To shed some light on this issue, the geometry of layout in Revit might be a number of digits and the NetLogo interface can define a limited distance of length and width. In other words, the unit of layout must be changed to a bigger unit for instance millimeter (mm) to meter (m). Figure 8 shows the geometry of main objects of layout (Walls, Doors and Windows) in NetLogo after importing. The physical aspect pf the model has been inserted in NetLogo environment. The framework of the space, size of the rooms and corridor has been defined in the NetLogo. Figure 9 shows the imported model. In the Next step the occupants' behavior will be modeled.

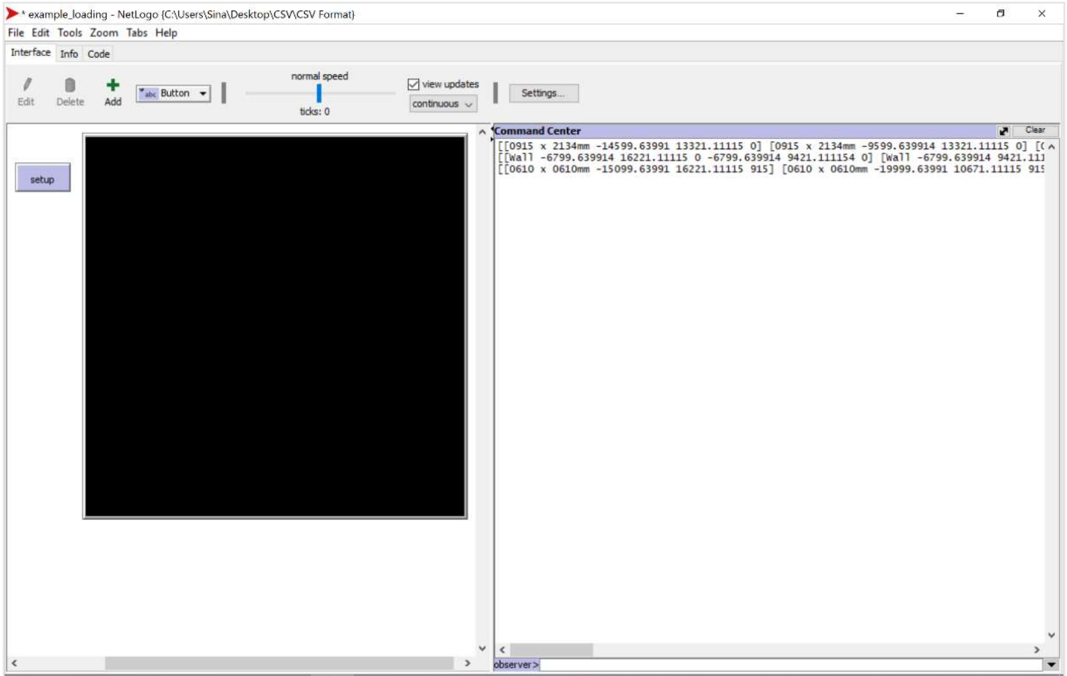


Figure 10: The NetLogo interface shows the imported data

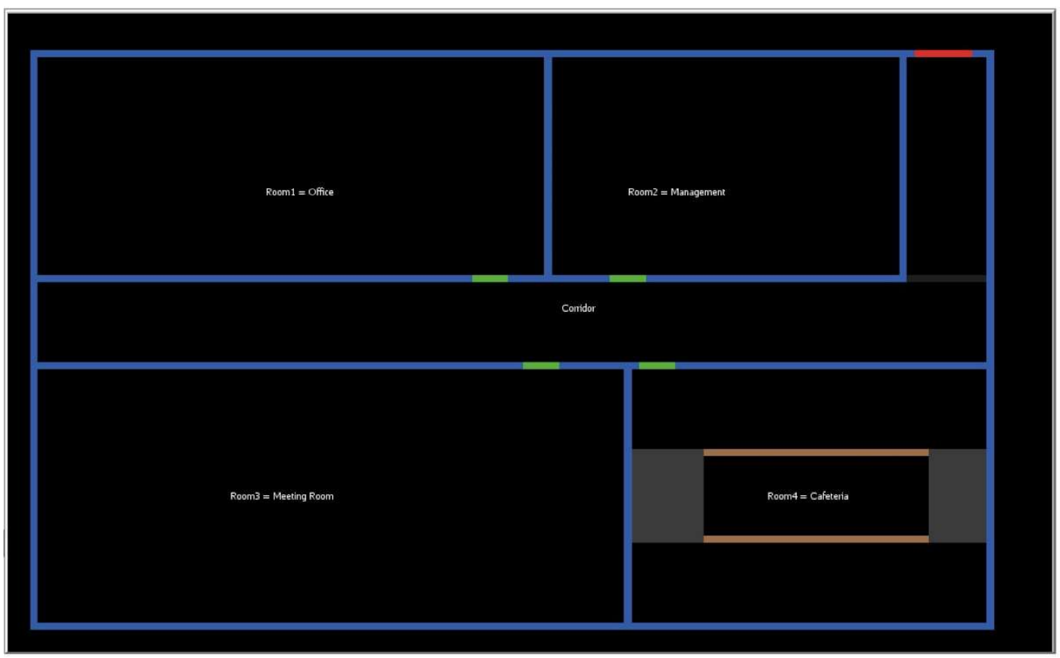


Figure 9: The imported model in NetLogo

Evacuation behavior modeling

The structure of model is determined in the NetLogo interface. In this step, the behavior and navigating people from their location to main exit should be modeled.

At the first step, the proposed model simulates the panic behavior for agents which they play the role of real people in the NetLogo world. For this purpose, the model assumed at the moment of happening a disaster, an initial scare exists in a bunch of individuals and this initial feeling. This reaction is originated in various factors such as gender, previous experience, education, etc. Thus, the percentage of initial scare depends on the characteristic of individuals which is not predictable.

The number of scared agents in each room can be set from 0 to whole agents of each room with a slider. Obviously, during evacuation the fear transmits from scared people to others. Hence, the models should meet the need of transmitting fear from scared agents (Red agents) to other agents (Yellow agents). The spread of fear changes via a slider which percent of spreading fear.

Another human's behavior must be considered to have more realistic simulation is the navigating agents from their locations to main exit. The panic reaction infects to other agents which is impacts on the speed and navigation of agents. The Figure 11 shows that how it happens in NetLogo coding.

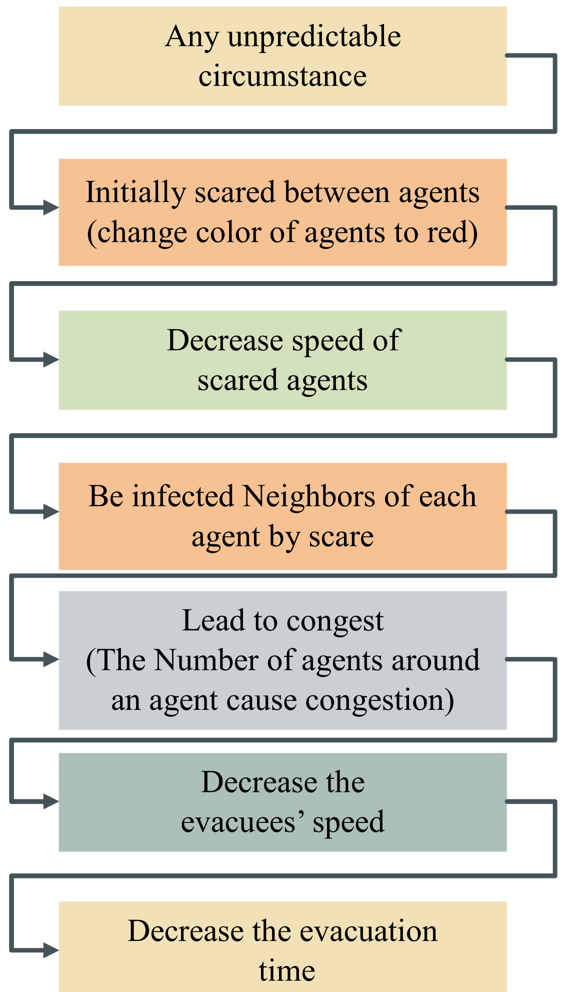


Figure 11: The process of evacuation behavior modeling in NetLogo

Assessment NBC provisions on the proposed model

In the wake of defining the physical and semantic aspect of the model, the dimensional aspect of NBC codes must be applied to the model to evaluate the affectability of the model to each measure.

Scattering agents in each room are randomly and the agents' locations in rooms are varied in each scattering, therefore, the distance of agents to room exits and density of them in each location affect the evacuation time. As a statistical rule to find a normal distribution the average of evacuation time should be less than 2 times of Standard Deviation (SD). Thus, to achieve the precise evacuation time, which is representative of the scattering agents, the model has been run with 25 iterations for each scenario. Furthermore, the maximum and the minimum amount of evacuation time have been between average $\pm$ SD.

The Egress National Building Code of Canada

The National Building Code of Canada (NBC) 2015 not only provides technical provision for the construction new buildings but also impacts on the altering use, demolishing and renovating projects [23]. This project focuses on the egress in emergency. Considering all standards and regulations, we extracted dimensional standard and requirement related to egress and the proposed model takes into account them. According the objectives of the project, following standards have been chosen:

- Occupant load
- Exit width
- Corridor width
- Door arrangement
- Distance to main exit

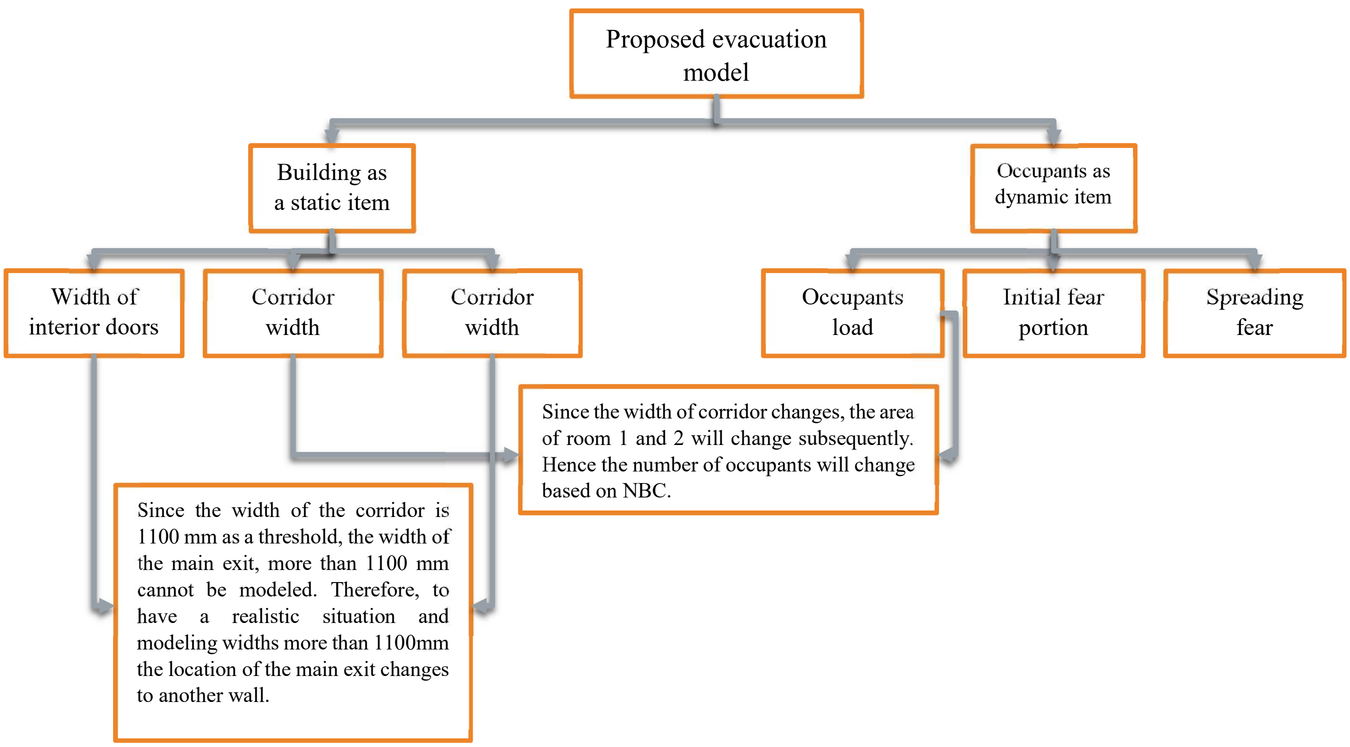


Figure 12: The interaction between dynamic and static items of simulating model

Occupant Load

This factor indicates the number of persons which such a space is designed. The article 9.9.1.3 of NBC mentions the occupant load and table 3.1.17.1 (Appendix 1) can be shown the area per capita in different uses. The area per person in a space with non-fixed seats and tables is 0.95[1] m^2 and with fixed furniture the minimum area per person must be 1 m^2 [23]. Hence, the appropriate number of occupants in each room of model can be calculated.

Table 2: The maximum number of occupants in each room of model

Room	Area (m^2)	Number of occupants*
Room 1	21	22
Room 2	14.4	15
Room 3	29.5	31
Room 4	18	18
*All number of occupants are rounded up.		

Table 3 shows the assumed measures for assessment the sensitivity of number of occupants.

Table 3: The other factors which assumed for assessment the occupants loads

The width of main exit	The width of interior door	Corridor width	Door arrangement
800 mm*	800 mm**	1100 cm***	1200 mm****
* The minimum width of exterior door according to NBC.			
** The minimum width of interior door according to NBC.			
*** The minimum width of corridor according to NBC.			
****The minimum distance between two doors in a series according to NBC.			
***** 50% of agents in each room have an initial scare and the scare infects with the 50% rate.			

According the threshold of NBC factors the sensitivity of evacuation time to number of occupants which were scattered in different rooms has been investigated. Table 4 and figure 14 show the average evacuation time for different scenario based on number of occupants.

[1] According NBC the minimum number of occupants in each room with one exit room must be less than 50 persons.

Table 4: the various number of occupants which has been scattered in rooms

Number of Occupants	-50%	-30%	-20%	Threshold	+20%	+30%	+50%
	43	60	69	86	103	112	129
Average Evacuation Time (sec)	53.60	80.46	107.08	207.54	280.45	296.12	334.47
Standard Deviation	3.2	4.9	5.1	44.5	47.4	56.3	56.3
Coefficient of Variation (%)	6.04	6.08	4.80	21.42	16.92	19.03	16.83

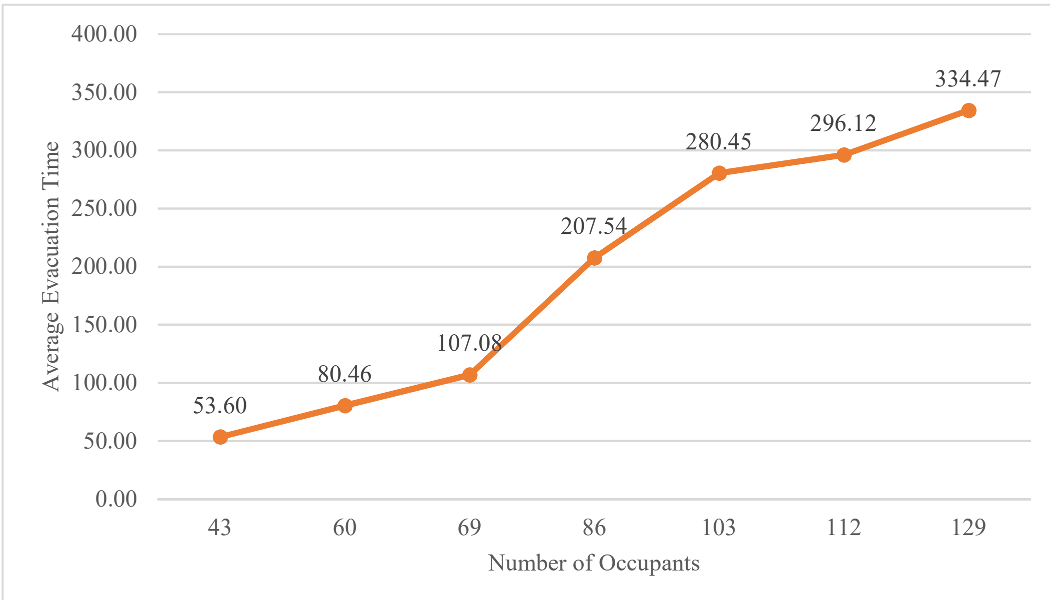


Figure 15: Time of evacuation for different number of occupants

Results:

- Although as NBC, the maximum number of occupants should be 86 persons, the time of evacuation between 69 and 103 which are 86 $\pm$ 20% has increased sharply.

The width of exits

According NBC of Canada, except for doors and corridors, the width of every exit facility shall be not less than 900 mm. Moreover, the door with one leaf cannot be less than 800 mm wide and not less than 1210 mm wide where multiple-leaf doors are installed with two active leaves [23].

As mentioned in literature review, a bunch of researches compared the width of door exit and main exit in different scenarios. In this part of report the width of doors of rooms and main exit must be assessed in NetLogo separately. For this purpose, different size of door for rooms and main exit have been selected from the market to estimate the evacuation time for each width of room door and main exit.

Figure 15: The direction of changes the width of the main exit

- **Assessment the width of room door**

For assessment the role of room door, other parameters should be fixed to predict the evacuation time for different width. Table 3 indicates the assumption for assessing size of room door.

Table 5: The assumptions are considered as a threshold for assessing width of room doors

The Load of occupants	The width of main exit	The width of corridor	Door arrangement
22+15+31+18 = 86*	800 mm**	1100 cm***	1200 mm****
*The maximum number of occupants in assumed unit based on NBC.			
** The minimum width of exterior door according to NBC.			
*** The minimum width of corridor according to NBC.			
****The minimum distance between two doors in a series according to NBC.			
***** 50% of agents in each room have an initial scare and the scare infects with the 50% rate.			

According to assumptions, different size of doors has been modeled in NetLogo to monitor the relation between the size of interior doors and evacuation time. The Table 6 and Figure 16 show the evacuation time for different size.

Table 6: Time of evacuation for different width of interior door

Width of Room Door (mm)	500	600	700	800	900	1000	1100
Average Evacuation Time (sec)	398.53	362.93	267.98	207.54	163.05	165.92	328.56
Standard Deviation	99.9	87.2	57.2	44.5	14.5	22.6	65.1
Coefficient of Variation (%)	25.06	24.01	21.34	21.42	8.88	13.63	19.82

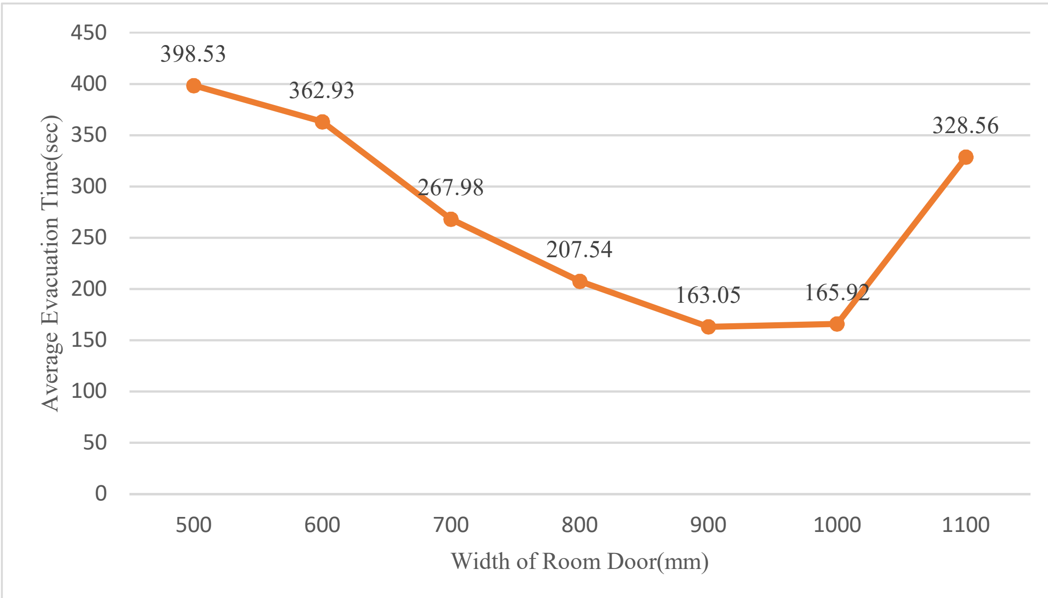


Figure 16: Time of evacuation for different width of interior door

Results:

- The evacuation time when the width of the room doors is between 500 mm to 900 mm decreases dramatically.
- The evacuation time when the width of room doors is between 900mm and 1000 mm do not change however, the time after 1000 mm grows up sharply.
- As mentioned in the previous researches shows that decreasing room door size improves evacuation efficiency in a certain emergency. Because the room doors decrease the crowd in the hallway causing the smaller density in the main exit.
- The proposed model shows the same results. The width of the main exit is 800 mm as a threshold in all different size of interior doors whereas, the evacuation time when the size of interior doors is more than the main exit, the evacuation time increases. The sharp decrease in 1100 mm shows the reverse result.

- **Main exit assessment**

For assessment the role of main exit, other parameters should be fixed to predict the evacuation time for different widths. Table indicates the assumption for assessing size of main exit.

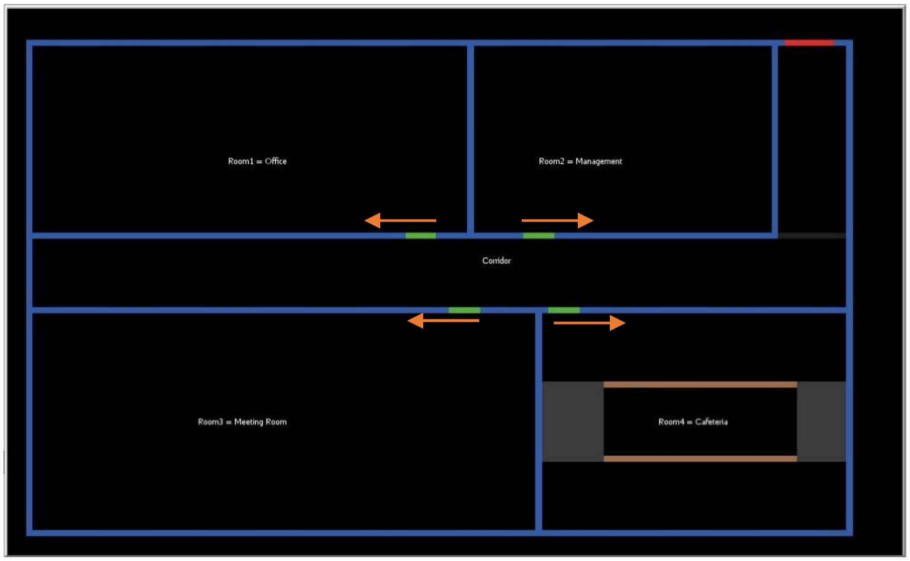


Figure 16: The direction of changes the width of the interior doors

Table 7: The assumptions for assessing width of room doors

The Load of occupants	The width of interior door	The width of Corridor	Door arrangement
23+13+31+19 = 86*	800 mm**	1100 mm***	1200 mm****
*The maximum number of occupants in assumed unit based on NBC.			
** The minimum width of interior door according to NBC.			
*** The minimum width of corridor according to NBC.			
****The minimum distance between two doors in a series according to NBC.			
***** 50% of agents in each room have an initial scare and the scare infects with the 50% rate.			

According to assumptions, different size of main exit has been modeled in NetLogo to monitor the sensitivity of the size of exit door on evacuation time. The Table 8 and Figure 18 show the evacuation time for different widths.

Table 8: Time of evacuation for different widths of exit door

Width of main exit (mm)	700	800	900	1000	1100	1200[1]	1300	1400
Average Evacuation Time (sec)	222.61	207.54	175.95	163.27	159.22	159.20	158.97	158.80
Standard Deviation	58.6	44.5	15.0	8.0	6.4	6.2	6.4	6.3
Coefficient of Variation (%)	26.31	21.42	8.50	4.91	4.02	3.88	4.02	3.95

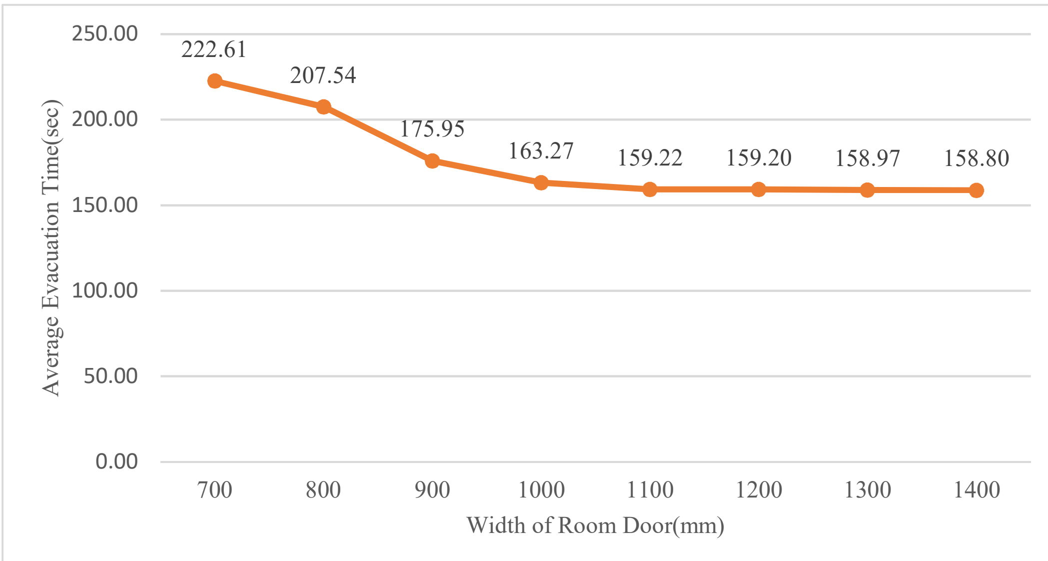


Figure 17: Time of evacuation for different widths of exit door

Results:

- Surprisingly, the evacuation time does not sensitive to the width of the main exit.
- As Figure 18 depicts, the exit door more than 1100 mm does not impact on the evacuation time.

[1]) Since the width of corridor is 1100 mm as a threshold, the width of main exit, more than 1100 mm cannot be modeled. Therefore, to have a realistic situation and modeling widths more than 1100mm the location of main exit changed to another wall. Appendix 2 shows the location of door for exits more than 1100 mm.

Corridor width

Respecting to NBC, the width of corridor, which is used by the public, and exit corridor shall be not less than 1100 mm [23]. Table 9 shows the threshold measures for assessment the sensitivity of width of corridor in different scenarios.

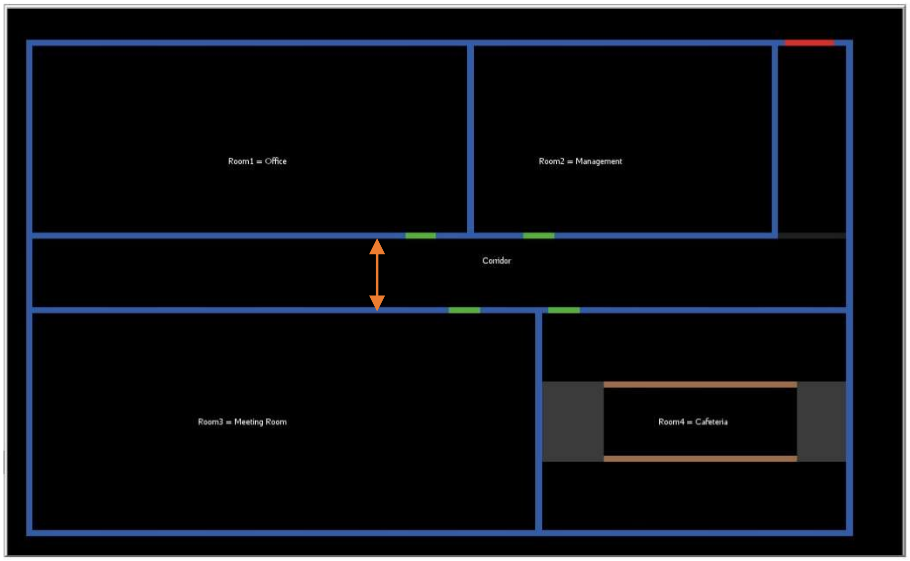


Figure 19: The changes of the width of corridor

Table 9: The assumptions for assessing width of corridor

The Loads of occupants	The width of interior door	The width of main exit	Door arrangement
23+13+31+19 = 86*	800 mm**	800 mm***	1200 mm****
*The maximum number of occupants in assumed unit based on NBC[1].			
** The minimum width of interior door according to NBC.			
*** The minimum width of main exit according to NBC.			
****The minimum distance between two doors in a series according to NBC.			
***** 50% of agents in each room have an initial scare and the scare infects with the 50% rate.			

The minimum width of the corridor cannot be less than 800 mm because of based on NBC the minimum width of main exit should be at least 800 mm. The table 10 shows the evacuation time for different width of corridor.

[1] Since the width of corridor changes the area of room 1 and 2 will change subsequently. Hence the number of occupants will change based on NBC (Appendix 1).

Table 10: Various evacuation time based on the width of corridor

Width of corridor (mm)	800	900	1000	1100	1200	1300	1400
Average Evacuation Time (sec)	287.99	250.46	213.67	207.54	192.92	173.78	171.32
Standard Deviation	55.3	44.7	31.8	44.5	25.7	17.9	17.1
Coefficient of Variation (%)	19.20	17.86	14.88	21.42	13.34	10.32	9.97

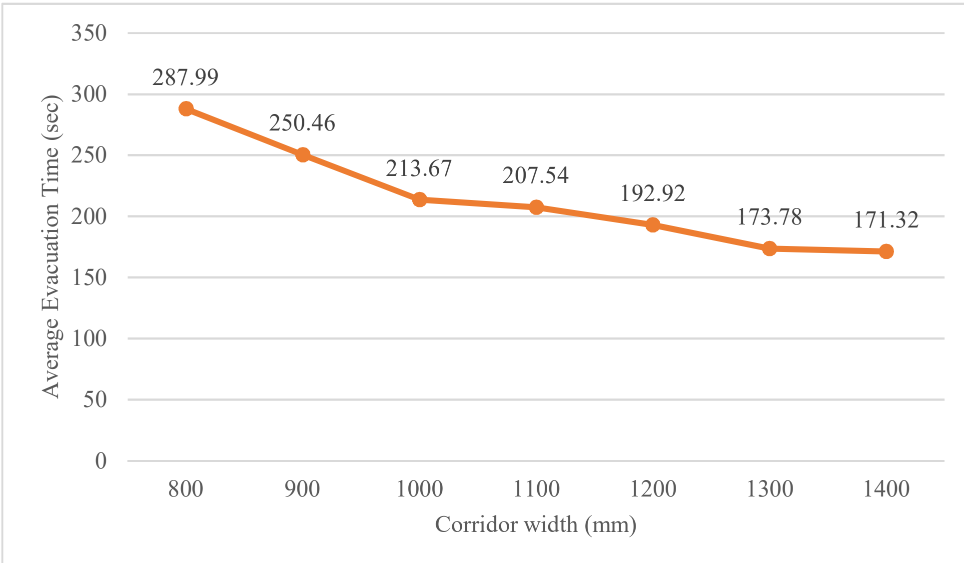


Figure 18: Time of evacuation for different width of corridor

Results:

- The slope of the chart under 1000 mm is sharp which illustrates that the evacuation time under 1000 mm is more sensitive to the width of the corridor.
- However, NBC determines 1100 mm for the minimum width of the corridor, the trend of changes after 1000 mm is steady.

Door arrangement

Based on NBC of Canada the space between two doors in a series must be less than 48 inches (1219 mm) plus the width of a door swinging into space [23]. This factor influences on the congestion. Since, people leave from their room, they collide on corridor. For that reason, the appropriate distance between two doors provide enough space to decrease congestion.

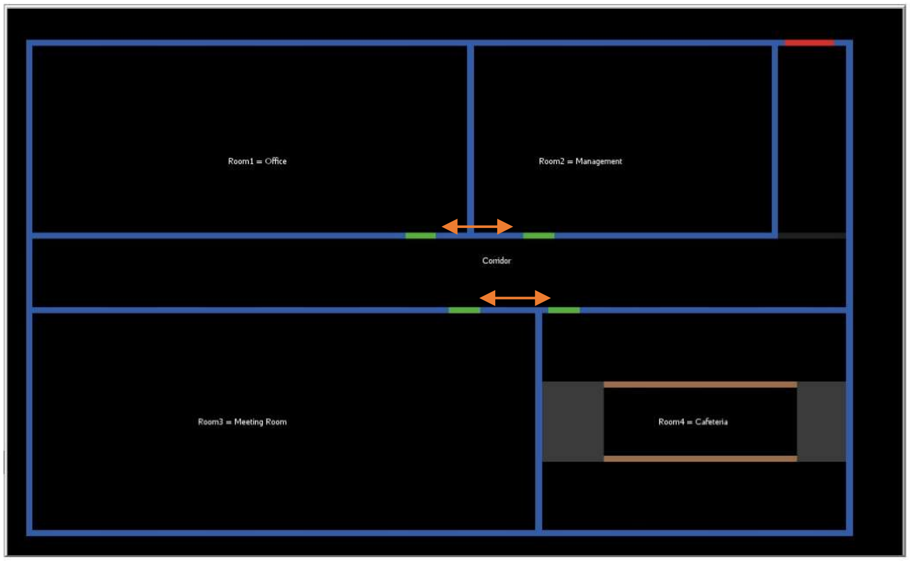


Figure 19: The changes the distance of door arrangement

To assess door arrangement, other parameters should be assumed to simulate evacuation behavior for different distance. Table 11 depicts assumptions as a threshold according to NBC.

Table 11: The assumptions for assessing door arrangement

The Loads of occupants	The width of interior door	The width of main exit	The width of corridor
23+13+31+19 = 86*	800 mm**	800 mm***	1100 mm****
*The maximum number of occupants in assumed unit based on NBC.			
** The minimum width of interior door according to NBC.			
*** The minimum width of main exit according to NBC.			
****The minimum width of corridor according to NBC.			
***** 50% of agents in each room have an initial scare and the scare infects with the 50% rate.			

The evacuation time are assessed base on simulated model for wide range of room door distance. Table 12 shows average evacuation time which is calculated from 25 iterations for 9 different measures of distance between two doors in a series.

Table 12: Evacuation time based on the various distance of door arrangement

Width of Room Door (mm)	400	600	800	1000	1200	1400	1600
Average Evacuation Time (sec)	320.75	288.41	283.55	227.08	207.54	196.75	223.48
Standard Deviation	103.6	79.4	76.7	38.2	44.5	28.9	51.8
Coefficient of Variation (%)	32.29	27.52	27.06	16.83	21.42	14.70	23.20

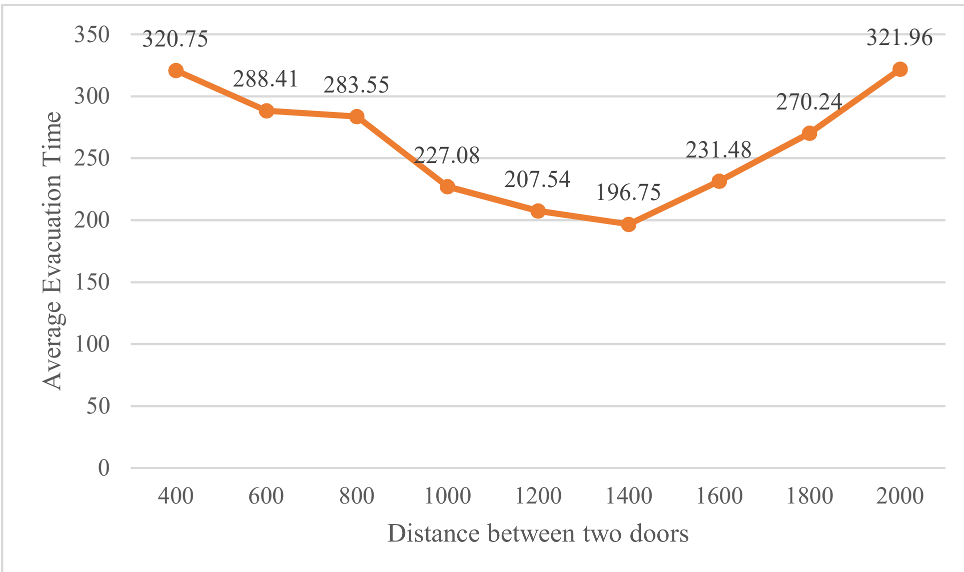


Figure 22: Various evacuation time based on the door arrangement

Results:

- As the results of the evacuation time of different scenarios show that the distance between 400 mm and 800 mm cause congestion.
- The evacuation time when the interior doors in a series between 800 mm and 1200 mm decreases sharply.
- Interestingly, the evacuation time increments when the distance is more than 1400. This wonder is an aftereffect of increasing the distance of the exit doors of room 1 and 3 to the main exit and the congestion between the exit door of room 2 and 4 when agents are fleeing from their rooms.

Evaluating the impact of panic behavior on evacuation time

The proposed model defines fear as a panic behavior amongst agents. The initial fear is felt by people at the beginning of the any disasters and as mentioned it depends on various factors. Then the fear spreads to other people who are near to scared person. The proposed model has tried to simulate the panic behavior as an initial scare and spread of scare amongst agents to simulate evacuation. Table 13 shows the assumption for modeling panic behavior amongst agents.

Table 13: Initial assumptions for proposed model to assess the panic behavior

The Loads of occupants	The width of interior door	The width of main exit	The width of corridor
23+13+31+19 = 86*	800 mm**	800 mm***	1100 mm****
*The maximum number of occupants in assumed unit based on NBC.			
** The minimum width of interior door according to NBC.			
*** The minimum width of main exit according to NBC.			
****The minimum width of corridor according to NBC.			

The evacuation time are assessed base on simulated model from 10 to 100 percent initial scare. This percent shows that the percent of people feel scare at the beginning of emergency situation. Moreover, it is assumed that the scare expands to other agents with the probability of 50 percent. Table 14 shows average evacuation time for 10 scenarios.

Table 14: The evacuation time base on changes in initial scare

The Percent of Initial Scare amongst agents	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average Evacuation Time (mm)	114.37	128.79	133.03	165.03	207.54	228.23	269.15	297.85	363.34	417.51
Standard Deviation	8.1	6.1	13.6	18.9	44.5	41.7	46.6	33.7	30.4	29.3
Coefficient of Variation (%)	7.12	4.70	10.24	11.47	21.42	18.26	17.30	11.33	8.37	7.02

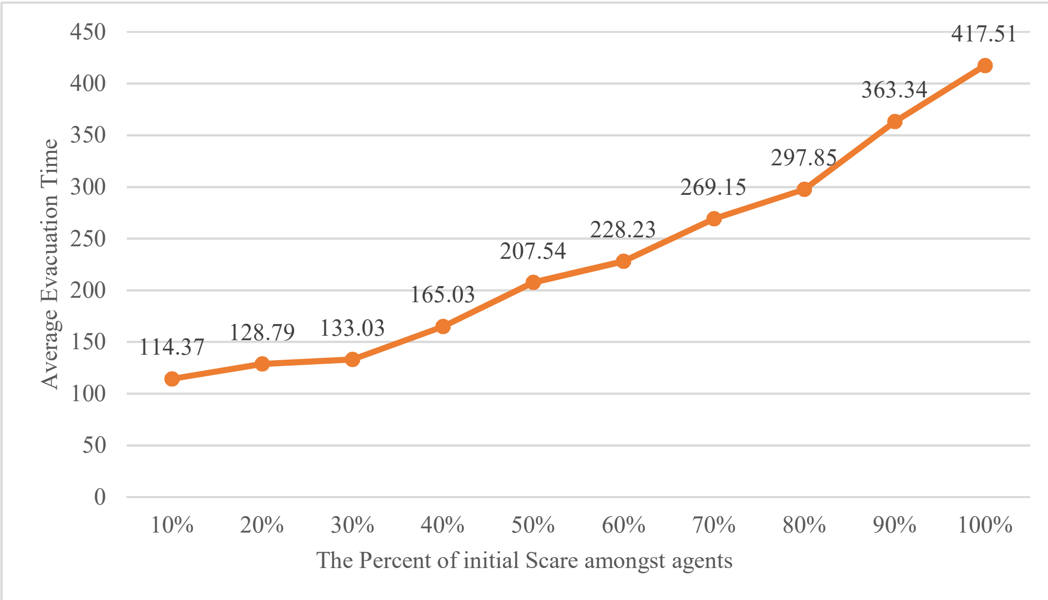


Figure 20: The evacuation time base on changes in initial scare

Spreading fear

At the second step, the panic behavior has been modeled according to changes in spreading fear to other agents. Table 15 depicts the evacuation time for various probabilities.

Table 15: The average evacuation time for various probabilities of expanding fear

The Percent of spreading fear to other agents	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Average Evacuation Time (sec)	167.28	186.71	194.72	199.67	207.54	213.20	231.00	237.04	240.03	256.85
Standard Deviation	17.6	36.0	33.5	44.1	44.5	53.5	33.7	30.5	29.0	31.0
Coefficient of Variation (%)	10.54	19.27	17.22	22.06	21.42	25.11	14.59	12.87	12.09	12.05

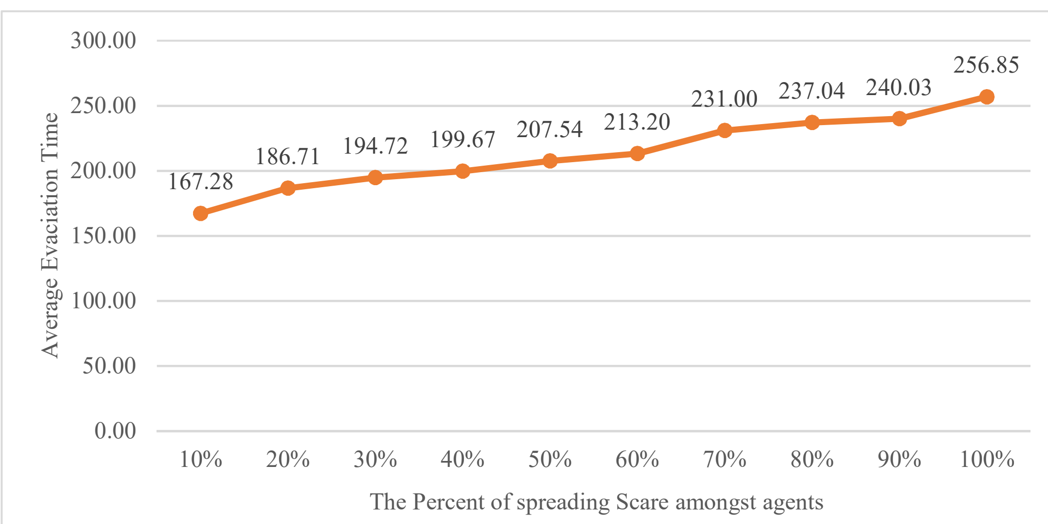


Figure 21:The evacuation time base on various probabilities of spreading fear

Results:

- As the results of two parameters shows the initial scare is more sensitive than the spreading fear on evacuation time.

Chapter 5: Results and conclusion

Spider and tornado graphs illustrate the variation of evacuation time according to the 6 criteria: occupants load, the width of the room door, the width of the main exit, initial scare, spreading scare, door arrangement and corridor.

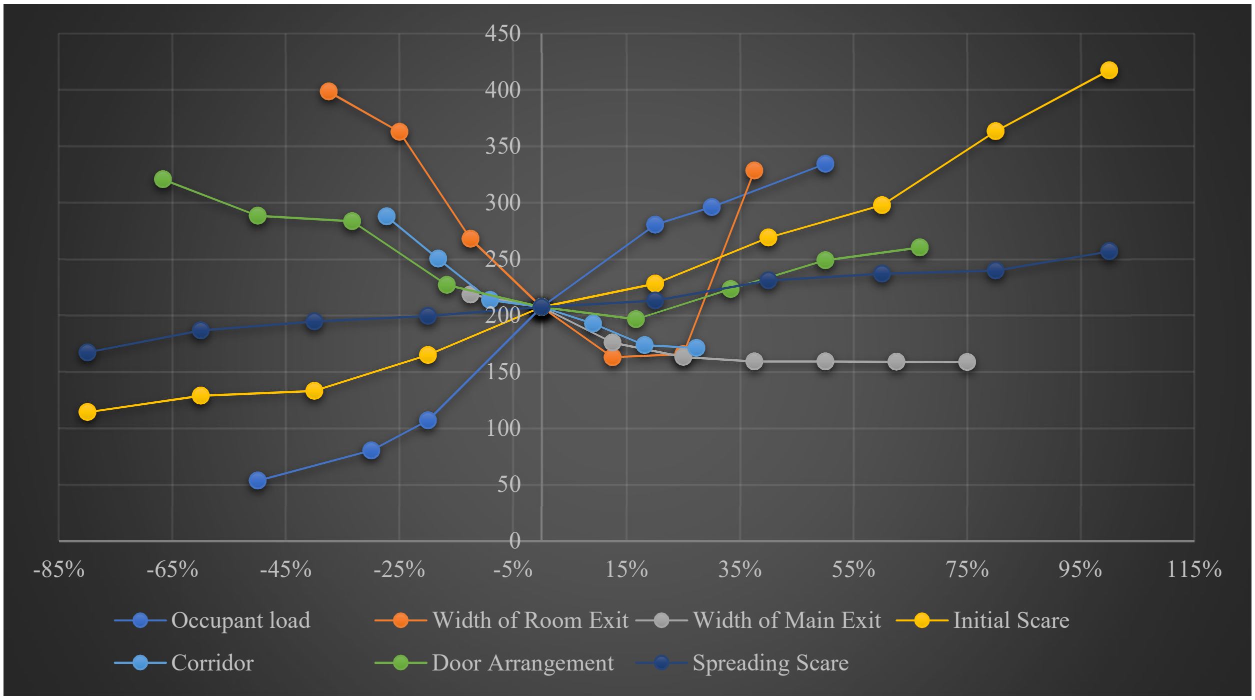


Figure 25: Spider graph of all assessed criteria

Figure 26: Tornado graph of all assessed criteria

The outcomes are depicted underneath:

- The result and contribution of the model is an improvement for evacuation planning.
- The proposed model
- The number of occupants is sensitive parameter which causes minimum and maximum time of evacuation.
- However, the width of the main exit has a negetive correlation with evacuation time, the width of the room door does not pursue this pattern.
- The evacuation time decreases dramatically when the width of interior doors increments between 500 mm and 900 mm. Surprisingly, the time of evacuation increases when the width is more than 1000 mm. It should be noted that the width of the main exit is 800 mm as a fixed number. Thus the ratio of interior doors to the main exit should not be more than 1, even if the width of both of them are more than the threshold.
- Although the evacuation time base on changes of distance two doors in a series is not drastic, the time of departure of agents increases when the distance is more than 1400 mm.
- Initial scare amongst agents and spreading fear are two human's features has a positive correlation with evacuation time.

Conclusion

This study follows two main objectives. Firstly, integrating BIM and ABM engines to simulate the interaction between occupants and physical components of the building layout. To achieve this purpose, the new model defines an algorithm to read the geometry of building components Revit with Dynamo as a visual programming language, then to import the hypothetical model in NetLogo as ABM engine for simulating occupants' behavior. The second objective is the assessment of the sensitivity of evacuation time to social and physical aspects of building design. To be more realistic, the model focuses on the micro level of detail including doors, windows, walls and main exit within NBC to simulate evacuation behavior in different scenarios. Moreover, the proposed model evaluates the sensitivity of static items of building code such width of the main exit, the width of interior doors, width of corridor, door arrangement and human's features such as occupant's load, spreading fear and initial scare with evacuation time via the open access engine NetLogo as an ABM engine.

The proposed model has a bunch of limitations which should be enhanced in future studies.

- The model has been simulated in NetLogo 6.04 as an ABM engine. Owing to the NetLogo determines space with setting features on cells which named patch thus, it is not possible to model non-rectangular shapes.
- Importing the geometry of building components necessitates reading the CSV file as the geometry data in NetLogo observer, then setting them as walls, windows, and doors in code space. However, this process defines semi-automated the static space in NetLogo for simulating evacuation behavior, it is a time-consuming process, especially for a large-scale model.
- Age, gender, disabilities impact on evacuation time significantly which should be assessed on future studies.
- In spite of the fact that the study defines an evacuation planning model for all building, the results of the model depend on the hypothetical building layout.

To further studies, it is possible to simulate non-rectangular building designs. Additionally, to improve the process of importing building components in the simulation atmosphere owing to increase the time of modeling complicated building layouts. Furthermore, to extend the outcomes of sensitivity analysis to whole buildings and to enhance building codes, the evacuation time should be assessed on the dozens of real models of various type of buildings.

References

[1] Q. Z. Z. D. X. Z. Y. Z. L. N. Y. L. a. Y. Z. Qing Xiong, "A dynamic indoor field model for emergency evacuation simulation," *International Journal of Geo- Information,* 2017.

[2] T.-R. Roan, "Developing an Agent-Based Evacuation Simulation Model Based on the Study of Human Behaviour in Fire Investigation Reports," University College London, 2013.

[3] V. Q. Ha, "Agent-based Modeling of Emergency Building," Master of Science at the University of Connecticut, 2012.

[4] M. C. &. A. S. Erik Andresen, "A representation of partial spatial knowledge: a cognitive map approach for evacuation simulations," Transportmetrica A: Transport Science, 14:5-6, 433-467, DOI: 10.1080/23249935.2018.1432717, 2018.

[5] Z. K. R. J. F. R. João Emílio Almeida, "NetLogo Implementation of an Evacuation Scenario," FCT (Fundação para a Ciência e a Tecnologia), 2010.

[6] M.-S. M. Hamed Faroqi, "Agent-based Crowd Simulation Considering Emotion Contagion for Emergency Evacuation Problem," in *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-1-W5*, Kish, Iran., 2015.

[7] N. Gaire, "A Study on Human Evacuation Behavior Involving Individuals with Disabilities in a Building," Utah State University, 2017.

[8] N. P. a. N. I. Badler, "Modeling crowd and trained leader behavior during building evacuation," *IEEE Computer Graphics and Applications,* pp. 80-86, 2006.

[9] Z. J. M. J. C. S. S. M.-R. J. G. J. I. T. &. S. B. Liu, "Interfacing Building Response with Human Behavior Under Seismic Events," *Johns Hopkins University, Department of Civil Engineering, United States of America,* 2012.

[10] A. R. M. K. Hosna Tashakkori, "A new 3D indoor/outdoor spatial model for indoor emergency response facilitation," *Building and Environment,* 2015.

[11] P. L. José Barbosa, "Simulation of multi-agent manufacturing systems using agent-based modelling platforms," EU Commission, Bragança, Portugal, 2011.

[12] C. S. H. K. D. K. H. L. Xiaoshan Pan, "A Multi-agent Based Framework for the Simulation of Human and Social Behaviors during Emergency Evacuations," *AI & SOCIETY,* vol. 22, no. 2, pp. 113-132, 2007.

[13] Z. Z.-m. C. J. Zhou Ying, "EcacAgent: A Building Emergency Evacuation Simulation Model Based on Agent," in *the 2017 International Conference*, Melborne, 2017.

[14] K. Zia, "Agent-based modeling oflarge-scale socio-technical systems in emergency situation," Johannes Kepler University, 2013.

[15] T. N. A. Nguyen, "Dynamic multilevel modeling in the design of decision support systems for rescue simulation: combining agent-based and mathematical approaches," HAL, Paris, 2015.

[16] W.Rand, "Machine learning meets agent-based modeling: when not to go to a bar," in *Agent 2006, Chicago.*, Evanston, 2006.

[17] G. K. T. ,. P. L. G. M. O. Sameera Abar, "Agent Based Modelling and Simulation tools: A review of the state-of-art software," *Computer Science Review,* pp. 13-33, 2017.

[18] S. L. L. S. K. J. Steven F. Railsback, "Agent-based Simulation Platforms: Review and Development Recommendations," *SIMULATION,* vol. 82, no. 9, pp. 609-623, 2006.

[19] X. L. F. W. a. C. C. Yuling Hu, "An Overview of Agent-based Evacuation Models for Building Fires," in *2012 9th IEEE International Conference on Networking, Sensing and Control*, Beijing， China, 2012.

[20] S. D. A. Matthew J. Berryman, Tutorials on Agent-based modelling with NetLogo and Network Analysis with Pajek, Melbourne: Monash University, 2009.

[21] C. Y. a. S. J. Chuanjun Ren, "Agent-Based Modeling and Simulation on Emergency Evacuation," *Social Informatics and Telecommunications Engineering,* pp. 1451-1461, 2009.

[22] R. D. P. Erica D. Kuligowski, "A Review of Building Evacuation Models," National Institue of Standard and Technology, Washington, 2005.

[23] C. C. o. B. a. F. Codes, National Building Code of Canada 2015, Ottawa: National Research Council of Canada 2015 , 2015.

[24] S. J. R. Stacy C. Marsella and David V. Pynadath, "PsychSim: Agent-based modeling of social interactions and influence," in *Cognitive Modelling, ICCM 2004,* , Pittsburgh, Pennsylvania, 2004.

Appendix

Appendix 1:

9.9.1.3. Occupant Load

1) Except for dwelling units, the occupants load of a floor area or part of floor area shall be the number of persons for which such areas are designed, but not fewer than that determined from table 3.1.17.1., unless it can be shown that the area will be occupied by fewer persons.

Type of use of floor area or part thereof	Area per person, m^2
Assembly uses:	
• Space with fixed seats	(1)
• Space with none-fixed seats	0.75
• Stage for theatrical performance	0.75
• Space with non-fixed seats and Tables	0.95
• Strada and grandstands	0.40
• Bowling alleys, pool and billiard rooms	0.60
• Classrooms	9.30
• School shops and vocational rooms	1.85
• Reading and writing rooms or lounges	1.20
• Dining, beverage and cafeteria space	4.60
• Laboratories in schools	
Care treatment or detention uses	
• Suites	(2)
• Care, treatment and sleeping room area	10.00
• Detention quarters	11.60
Residential uses	
• Dwelling units	(2)
• Dormitories	4.60
Business and personal services uses	
• Personal services uses	4.60
• Offices	9.30
Mercantile uses	
• Basement and first storeys	3.70
• Second storey having a principal entrance from a pedestrian	3.70
thoroughfare or a parking area other storey	5.60
Industrial uses	
• Manufacturing or process rooms	4.60
• Storage garages	46.00
• Storage spaces (warehouse)	28.00
• Aircraft hangers	46.00
Other uses	
• Cleaning and repair goods	4.60
• Kitchens	9.30
• Storage	46.00
• Public corridors intended for occupancies in addition to pedestrian travel	3.70

Appendix 2:

The location of exit door in scenarios which the width of the main exit is more than 1100 mm.