USING AGENT-BASED MODELING TO CALCULATE AN EASE SCORE: EVACUATION WITH ACCEPTABLE SIMPLICITY IN EMERGENCIES

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ABSTRACT

This research seeks to provide a metric for the ease of evacuating a building in case of fire. The proposed Evacuation with Acceptable Simplicity in Emergencies (EASE) score combines multiple metrics related to code compliance, path simplicity, exit availability, total travel, and congestion that were calculated from agent-based simulation. The agent-based model was created in open source software called BuildingComplexity, a Unity software application designed to allow novices to model building floorplans quickly. Results for seven buildings are presented. An attempt at EASE score validation through human surveys revealed participants' challenges in interpretating of floor plans consistently. The BuildingComplexity software offers an agile, iterative alternative for assessing evacuation ease, and while not fully validated, the EASE score demonstrates a useful proof of concept for quantifying patterns of building layouts that might be otherwise difficult to describe.

Keywords: evacuation, building information model, fire, floorplan.

1 INTRODUCTION

Historically, building designs with improper exit strategies have led to tragic loss of life. In 2003, an incident known as the Station Nightclub fire occurred in W. Warwick, Rhode Island, USA that claimed the lives of 100 people and injured 230 others [1]. When the fire broke out and the alarms activated, the crowd instinctively rushed towards the door they had used to enter, creating congestion in a narrow hallway. While the first exit became overburdened, there remained four others available. Similarly, the 1903 Iroquois Theater fire in Chicago, USA, is remembered as one of the deadliest single-building fires in the country's history. This incident cost 602 lives and left the fire codes of the day under intense scrutiny [2]. These incidents illustrate the necessity of assessing building layouts for appropriate evacuation methods.

By assessing how well a structure facilitates evacuations, these incidents could be mitigated. However, there is currently no systematic way to rate a building’s ease of evacuation. Additionally, the current metrics for evaluating evacuation success are not effective when comparing different buildings. For example, there is no metric that one can use to argue that Building A’s design promotes evacuation twice as efficiently as Building B’s design. Although a building might not typically be framed as “technology,” an evacuation outcome is heavily influenced by building simplicity and physical accessibility, much like with the use of technology. Thus, the authors suggest that principles of human-computer interaction and cognitive engineering can inform the creation of such a metric.

The present paper describes a new open-source Unity software application called BuildingComplexity that enables the easy creation of a building floorplan and agent-based model (ABM) simulation of evacuation

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in the pursuit of calculating an EASE score (Evacuation with Acceptable Simplicity in Emergencies), a rating of the ease of building evacuation. The concept of the EASE score was motivated by 71 surveyed users' inability to make consistent judgments about the difficulty of evacuation based on floorplans. While designers cannot predict the various circumstances of a building disaster, including its origin and magnitude, an EASE score could be used to quickly evaluate a layout's ability to facilitate an exodus. While many other software simulations of building evacuation exist, this paper focuses on the ABM used within BuildingComplexity, the ease of use of the software, and its facilitation of the comparison of different possible EASE scores. By employing agent-based modeling (ABM) in this context, we aim to contribute an aid to building design as well as emergency planning to safeguard human lives during evacuation.

2 RELATED WORK

2.1 Current Approaches to Evacuation

To give background for this study, this section describes factors influencing evacuation in previous studies and a review of previous evacuation modeling tools.

Before describing Building Information Modeling (BIM) tools and factors for evaluating building complexity for evacuation purposes, it is appropriate to note the theory of space syntax by Bill Hillier, which has evolved from a theory in the 1970s [3] to a set of computational tools like depthmapX in more recent decades. Space syntax attempts to evaluate the complexity of both cities and buildings in terms of mobility and sight lines, and it shares some of the same goals as evacuation simulations. For example, Hillier's concept of intelligibility offered a metric of how well a local environment was integrated with the larger scale environment based on the number of connections [4, 5]. Presumably in a more intelligible region, exits would be easier to discover. While it is still in use by some architectural communities, space syntax does not offer a computational or formulaic method of scoring the ease of evacuation of a building that might satisfy an engineer. One might suggest that a measure of evacuatability could be designed based on room connectivity and number of exits, for example, but such a measure would omit any consideration of the interior design and wayfinding signage of a building, which would depend on occupants' lines of sight and ability to view exit signs and other cues for evacuation. Thus, there is still a need for an EASE score, and because of the interest in interior lines of sight, and agent-based model is appropriate.

Previous research on factors that influence evacuation has emphasized exits and travel distance [6], as well as smoke [e.g., 7]. Exits need to be accessible to people at a reasonable distance and time. Thus, improving building safety can include adding more exits, simplifying the path to an exit, increasing ceiling height, or increasing their visibility. Therefore, a better-designed building minimizes the maximum required travel distance, which includes mitigating instances of path retracing [6]. The International Building Code (IBC), developed by the International Code Council, adopted building code standards containing all details needed to be considered during the design phase. It provides details such as the number of exits and the size of means of egress based on the functionality of the space and occupant load.

Evacuation calculations are a crucial part of analyses to determine the level of safety of a building. Engineers used to use hand calculations to assess it, following the equations provided in the Emergency Movement Chapter of the Society of Fire Protection Engineers (SFPF) Handbook [8]. In this approach, it is assumed that occupants are standing at the doorway to the stair when the evacuation begins. The main focus is on constriction points and times occupants need to pass by them to the outside. More recently, engineers have looked to computer-based models for more realistic simulations and the use of evacuation models has increased [9]. NIST, the National Institute of Standards and Technology, has done many reviews and studies of building evaluation models [10]. They all provide evacuation model introductions and help users pick the most appropriate one for a certain scenario.

Another significant factor that can change evacuation efficiency is the psychology of the people exiting. In moments of panic evacuation can become a dangerous process if the group moves in a mob and has the very real possibility of trampling over someone in their panic. The design of the building and the stress it causes to the inhabitants can drastically affect the speed and bottlenecking of an evacuation [11]. Motivation to leave a building when there is a shooter or a fire seems straightforward. However, some people freeze when faced with a dangerous situation, and one of the approaches in evacuation research is the panic approach [12]. Motivation to evacuate and how a person gets to the reaction they do can be changed by many factors like knowledge of nearest exit, training, and previous fire experience.

Smoke can be a huge factor in fire evacuation, and other evacuations have implemented some form of smoke tracking [e.g., 7]. BuildingComplexity does not currently use any smoke simulation, and is focused instead on the 2D layout of a building. However, ceiling heights and smoke simulation could be added.

The BuildingComplexity software currently includes the factors of time to evacuate, travel distance, number of doors required to exit, and how well exit usage is equally distributed among evacuees. It does not currently consider, the density of a crowd at doorways or mob mentality, but these could be added for future exploration.

2.2 Existing Tools

There are many evacuation models all with strengths and drawbacks. See [13] for a review of over 600 papers on ABM in architecture more generally, and [14] for a brief overview of evacuation simulation models in particular. Models range in the factors they include for consideration, for example, smoke movement, evacuation time, congestion of evacuation, and others. The tool ESM [14] shares a similar goal to the current project in that it seeks to categorize the safety of a floorplan, focusing on the layout of the building using nodes and arcs to not only predict evacuation paths but also determine if there are places agents could get trapped. However, the ESM project does not propose a final measure for ease of evacuation.

There are two types of evacuation simulation models, macroscopic and microscopic [15], also called coarse and fine networks [14]. Microscopic or fine models typically divide a floorplan into tiles or a grid, each of which could be occupied by an agent. These models require more computational power but can model individual movements through detailed spaces and individual differences between different people or agents. The macroscopic or coarse models use spatial nodes representing each larger space (e.g., a room or portion of hallway) to map a building to predict evacuation times, congestion, and possible layout design flaws. These models are computational simpler and run faster, but do not typically distinguish the movements of different agents that share a similar path. Traditionally, ABMs are often categorized as microscopic models due to their capability to simulate individual agent movements within a space. However, our simulation, BuildingComplexity, aligns more closely with the macroscopic or coarse approach, where spatial nodes represent significant areas within the building rather than individual tiles.

A BIM called EVACNET4 simulated the evacuation of a library, for example, using nodes with a focus on bottlenecking [16]. It is worth noting that different evacuation models that use nodes may still use different assumptions and even metaphors for evacuation. EVACNET4 has a particular focus on the "arc," for example, which is the congestion of the nodes in space showing the bottleneck points. ESM [14], on the other hand, has a flow model, modeling evacuees in hallways like water flowing through a piping system. It is unclear how these different underlying metaphors using in design of the simulations affect their output. BuildingComplexity, the tool discussed at present, uses an agent-based model, which could, for example, lead to over-reliance on its results if the agents are perceived to be sufficiently human-like when they do not in fact behave as actual humans would [17].

While the history of building simulations of evacuation seems at first glance to be a story of progress and ever-higher fidelity, fueled in part by increased computing power, some argue that this story is a false narrative [18]. In contrast, that author suggests that numerical simulations can have an illusory compellingness [19] while the dynamics of fires and crowds vary in such unpredictable ways that we cannot yet claim victory over evacuation modeling. In this light the BuildingComplexity tool, designed to be quick and easy to use for iterating over multiple models, even if the models are simplified, may offer an agile, iterative alternative to highly computational and complex tools.

3 METHODS

3.1 The BuildingComplexity Tool

Built in the Unity game engine, BuildingComplexity (https://github.com/Noah-Hall/BuildingComplexity) is a BIM that uses snappable, LEGO-like components such as floors, walls, doors, and pre-built rooms to allow a user build a Unity model of a building based on a floorplan within 2-5 hours, depending on the floorplan complexity. BuildingComplexity's workflow allows the user to create a layout without the use of other software such as Revit or AutoCAD, get quantitative feedback, and use the feedback to make layout improvements. A stairs component allows the creation of multifloor buildings that are represented in BuildingComplexity as multiple 2D floorplans connected with stairs. BuildingComplexity includes an agent-based simulation model, integrated in the Unity codebase, that allows the user to place agents into each room and run evacuation simulations. The ABM is described in full detail below.

3.2 The BuildingComplexity Agent-Based Model

The organization of this section follows the overview, design concepts, and details (ODD) protocol [20, 21] established for describing ABMs.

3.2.1 Purpose

The purpose of the BuildingComplexity ABM is to evaluate the ease of evacuation (or "evacuatability") of a building based on its floorplans. This ABM is based on the theory that by populating the rooms of a floor plan with agents that have a goal of evacuation and running the simulation, one could establish an EASE score for ease of evacuation based on the results of the simulation. Several underlying assumptions of this theory are described below.

3.2.2 Entities, State Variables, and Scales

Entities are the objects in the model that interact with each other. The BuildingComplexity ABM contains two overall entity types: agents (who move in the x,y plane of the floorplan evacuate) and static navigational targets with which agents interact (exits, doors, stairs, hallways, hallway intersections). Some targets are spatial nodes, that is, room nodes or hallway nodes or hallway intersection nodes. The building itself, the environment, is measured in meters within Unity and also has several parameters that accompany it. Agents move at a speed of 1.24 meters per real-time second of the simulation (the simulation currently runs in real time, so that a 2-minute evacuation requires 2 minutes of actual time, but the processing could easily be sped up if desired). Thus, the state variables used to describe these entities are shown in Table 1.

3.2.1 Process Overview and Scheduling

The update process consists of focusing on each agent one at a time, in the same order (foreach(agent)), to update its movement towards the most appropriate target per the priorities illustrated in Figure 1. Agents may not move through walls.

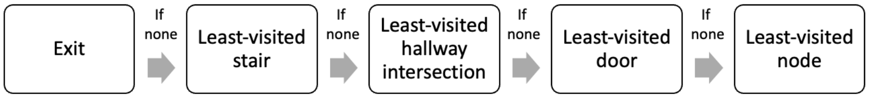

Figure 1: The EASE Tool's decision-making model used by agents for navigation. This model places different priorities on targets that may be in line of sight for the agent.

Table 1: The entities and state variables of the BuildingComplexity ABM.

Agents
• Agent ID – unique identifier. • Position X, Y – tracks physical location of agent. • Weight – integer value which if greater than one, counts as multiple agents. Defaults to one. • Distance traveled – total distance which the agent has traveled. • Targets visited – dictionary of visited targets and number of visits per target.
Targets
• Target ID – unique identifier. • Position X, Y – tracks physical location of target. • Agent visit (Agent ID, time) - tracks agent visits to target. • First visit time – tracks time stamp of first visit. • Last visit time – tracks time stamp of last visit. • Number of agents visits – tracks total number of agent visits.
Building
• Square meters – total area of floorspace within the floorplan. • Number of floors – total number of floors within the floorplan. • Number of exits – total number of exits within the floorplan. • Number of stairwells – total number of stairwells within the floorplan. • Number of doors – total number of doors within the floorplan. • Number of nodes – total number of nodes within the floorplan.

3.2.2 Design Concepts

Basic Principles: Agents spawn in all rooms of a given floorplan with no initial knowledge of the floorplan. Agents must search for exits or other targets to evacuate the floorplan. *Objectives*: An agent's priority of navigational targets (objectives) is described in Figure 1. *Emergence:* A key pattern that can emerge from BuildingComplexity simulations is the idea of **late evacuators**. In a building, for example, it may be that 90% of agents evacuate within 60 seconds, while the last 10% of agents (late evacuators) require more than 3 minutes to evacuate. *Adaptation & Learning:* Agents learn based on the memory of targets which they visit. They use a dictionary of visited targets to determine which target in line-of-sight to move towards next. The agents do not learn other than this memory of visited targets. *Prediction*: The agents do not make predictions; they simply seek the next target. *Sensing:* Agents can sense targets within line-of-sight, which is defined as 360° FOV at a range of 50 meters. Targets are defined by users setting up the building floorplan such that it is unlikely that there would be no target in view.

Interaction: Agents do not interact with each other; they act independently. *Stochasticity*: Agents do not currently feature stochasticity, but that feature could be easily added to BuildingComplexity. *Observation:* Raw data variables collected are show in Table 1, and derived variables include descriptive statistics for each raw variable, e.g., average agents per node and average nodes visited per agent; minimum, maximum, mean, and median evacuation time.

3.2.3 Initialization and Input Data

Agents are spawned on "Room Nodes" (targets which represent a room). Agents weight value corresponds to the weight value of the "Room Node" which it is spawned at. Agents have no prior knowledge of the floorplan or building. The only input data agents receive is the collection of targets in their line-of-sight. Targets are given a value based on distance from the agent and the priorities described in Figure 1. A greedy algorithm chooses the highest value target.

3.3 Assumptions and Agent Decision Making

Agent functions and attributes were selected to reflect a worst-case scenario, that is, evacuees have no memory of their building and no assistance in their route selection. In BuildingComplexity, this approach means that at the beginning of the simulation, agents have no cognitive map of the building, their current location, or memory of an entrance. Since many humans attempt to exit using the entrance they used, rather than the closest exit [22], these simpler agents likely differed from humans at this stage.

Additionally, all agents act independently. Because navigation can be affected by observing the behavior of others, agents are essentially invisible to one another. This leaves only the physical space around an agent, including door placement or visibility, to use in locating an exit. If two agents happen to approach each other during simulation, they cannot collide. It is worthwhile to point out that making agents behave independently of one another ignores congestion effects which can lead to low performance evacuation scenarios. Several variables contributing to the EASE score, such as "maximum number of visits to a node" were recorded to capture potential hazardous congestion during egress and mitigate this issue. Agents were chosen to not affect one another so the EASE score could capture navigation difficulty from all potential starting points in a building. A future version of BuildingComplexity could include agent collision and congestion.

Because agents do not interact with one another, one may question whether this simulation is truly an agent-based model. However, the fact that agent decisions are based on individual cognitive models (the priority rules in which they search for an exit) and the fact that the agents interactive with the building seem to justify the use of the term "agent-based model" (ABM). Also, each agent helps visualize the path that would be taken by human individual evacuating from that region of the building.

Each floor plan begins with one agent spawning on each room node. Although this means there is only one agent per room, weights relating to the population of a room can be assigned to each agent so that variables contributing to the EASE score are proportionate to each expected room population. This distribution of agents (as opposed to many agents in a larger room and fewer in smaller rooms) is useful for calculating the typical evacuation times and paths from each location within the building, which then offers a measure of the rooms which require the longest evacuation time. A future version of BuildingComplexity that includes agent congestion would be appropriate for measuring the maximum safe occupancy of each room.

During the simulation, there are no environmental influences on evacuation success such as smoke or blocked paths. This was done because the origin, type, and magnitude of a potential disaster is not predictable. Thus, the EASE score would provide a rating focused on the availability, visibility, and spread of potential exits, rather than a rating attuned to a specific disaster type. Thus, the EASE score may not be predictive better in a disaster which obstructs a section of a building, unless many other exits are available.

To best represent a building's complexity and its difficulty of navigation, a decision-making model was constructed to guide the agents in prioritizing various navigational targets during evacuation, such as stairs, exits, doors, and hallway intersections (Figure 1). Agents follow a predefined set of rules where they seek out the following targets in order of priority based on each agent's individual perception of the building environment (inspired by the cognitive modeling of wayfinding [23]). Agents assess the visibility and accessibility of nearby targets within their line-of-sight, without considering the movements or experiences of other agents. An agent's first priority if not on the lowest floor is to navigate to the ground level via stairs. Otherwise, agents prioritize traveling to exits within their line-of-sight. If no exits are available, agents travel to unvisited hallway intersections. This was implemented because of behavior noticed in early simulations of agents; without a hallway intersection priority, agents with no exits in sight would search other interior rooms for exits before progressing further down a corridor. Only if there are no intersections in sight will agents travel through other non-exit doors. If non-exit doors are unavailable, agents will travel from node to node using the "navmesh" built into the floorplan by the EASE Tool. At each priority level (stairs, exits, intersections, doors, and nodes), agents will prioritize those which have not been visited previously. This limits any "doubling back" by agents until they have exercised other novel paths to a potential exit.

3.4 The EASE Score

To quantitatively evaluate the ease of evacuation for a building, appropriate parameters for a model needed to be selected. Based on the literature review on past evacuation modeling and interviews with building safety professionals, the authors propose a framework to encompass the most significant categories influencing evacuation success. Particularly, these categories are related to the building's physical features and evacuee travel. The selected categories include code compliance, path simplicity, exit availability, total travel, and congestion. Measurable factors, shown in Table 2, were selected to fit the categories of this framework, and were collected in an output log for each simulation. The EASE score was designed such that a lower EASE means the building is easier to evacuate. A weight was chosen for each factor that would scale that each factor's range to approximately 0-100. These weights would need to be refined in the future based on wide range of buildings but serve as a reasonable approximation at this point to explore the EASE score as a proof of concept. Weighted factors were then averaged to calculate the EASE score, which ranged from 0-100, where 100 is most difficult to evacuate.

Table 2: Factors selected for inclusion in the EASE score and their categories of evacuation concepts. Weights were chosen that scaled each factor to a range of 0-100. The EASE score is the average of the weighted score factors.

EASE Score Factors	*Weight*	*Code Compliance*	*Path Simplicity*	*Exit Availability*	*Total Travel*	*Congestion*
IQR of Travel Times (s)	2		X	X	X	
Max Travel Time (s)	0.8		X	X	X	
IQR of Travel Distances (m)	1.5		X	X	X	
Max Travel Distance (m)	0.65		X	X	X	
IQR of Doors Per Agent	8	X		X		X
Max Doors Per Agent	3	X	X	X	X	X
Max Agents per Door	4	X		X		X
Max Percentage of Exit Use	150	X		X		X
Sq Meters/Exit	0.06	X				X

Because some metrics can have non-normal distributions (such as the number of agents who visit each door), Interquartile Ranges (IQRs) are applied to multiple metrics as a measure of variance. It is predicted that higher variance in these metrics (higher IQR) will indicate that a building is more difficult to evacuate, thus increasing the EASE score. For example, buildings with less varied exit paths for each agent will result in lower EASE scores, and a low IQR of Agent Travel Times implies that agents have similar travel times.

One cause for concern within EASE is the lack of congestion simulation, since agents travel independently to one another. However, several metrics can be used to capture potential congestion based on agent paths. Max Agents per Door serves as a measure of congestion, as does the Max Percentage of Exit Use (ideally exits would be used equally).

Some metrics within the EASE score are expected to favor different building sizes. For example, the Max Travel Time contributes to a greater EASE score, meaning that larger buildings, regardless of the safety of their design, will have a higher EASE score because occupants must travel further to an exit, and smaller buildings would be favored. The authors suggest that this outcome is acceptable, since time is a significant factor in building safety. Therefore, two identical buildings which vary only in proportion should have different scores. Building size is expected to have effects on other metrics as well and retain their usefulness through similar reasoning. Thus, comparing buildings which differ in size is still possible with the EASE score. As EASE's validation data is expanded to include buildings of more varying size, issues with extrapolation will be mitigated.

Because the origin of a disaster could in theory begin anywhere on a particular floor, the EASE score was also built to assess the availability and accessibility of all exits. This is done by measuring both the maximum percentage of a building's population that uses a particular exit and the average time to reach any exit. Because agents in EASE begin the simulation with no memory of the layout of the building, exits that are reached by fewer agents or later in the simulation would likely result in a higher EASE score, since they are harder to find.

4 RESULTS

4.1 Comparing EASE Scores

To generate data, seven buildings were modeled using BuildingComplexity (Figure 2). All buildings were already constructed and in-use, and all but one of them was part of the local university campus. They were chosen to represent a varied range of sizes (D is only 6,747 sq ft, while A is 13,779 sq ft), range of symmetry (G and D have axial symmetry and C has some radial symmetry, while F has very low symmetry), and range of room nesting (the percentage of rooms which are adjacent to a main hallway, related to Hillier's intelligibility; B and F have more rooms off the main hall).

Figure 2: The seven floorplans explored with ABM and human surveyed ratings. A Red E indicates Exit.

A simulation was run using BuildingComplexity for each of the seven floorplans. One agent was placed in each room of the building, and then each agent followed the Figure 1 procedure to locate an exit. Results are shown in Table 3, ordered by EASE score.

Table 3: The simulation results for the seven buildings, sorted by EASE score (green). Building specifications (orange), and values for the EASE score metrics (blue) are also provided.

Building	**EASE Score**	Square Meters	Exits	Agents	IQR of Travel Times (s)	Max Travel Time (s)	IQR of Travel Distances	Max Travel Distance	IQR of Doors Per Agent	Max Doors Per Agent	Max Agents Per Door	Max Percentage per Exit	Sq Meters/Exit
D	**33**	6747	4	35	10.6	37.2	13.6	42.8	1	10	4	31%	1687
E	**43**	4407	9	40	30.3	56.3	35.5	69.3	1	6	15	43%	490
G	**49**	6600	4	24	10.8	64.6	13.1	75.1	5	14	13	46%	1650
C	**69**	4115	4	38	53.4	102.2	65.4	126.5	3	15	7	63%	1029
B	**69**	7902	6	47	28.1	113.9	34.0	134.9	3	21	24	53%	1317
A	**72**	13779	5	44	21.6	127.4	27.2	155.4	4	24	12	34%	2756
F	**76**	10193	11	52	30.0	124.0	36.4	149.8	12	35	17	33%	927

4.2 Attempt at EASE Score Validation

To validate the BuildingComplexity ABM-based EASE scores, the authors surveyed 71 participants in an IRB-approved study from architecture and construction engineering within a large university. Within the survey, floor plans of the seven selected buildings were presented in random order with exits labeled. For each floor plan, participants were asked, "Imagine being inside one of the rooms of this building. How easy would it be to evacuate this entire building in the case of an emergency? Rate on a scale of 0-10 (with 0 being "extremely difficult" and 10 being "extremely easy"). While this current paper does not discuss the results in detail, the overall conclusion of the survey was a confirmation of what architects whom the authors spoke with know from experience: most people do not know how to interpret floor plans. This conclusion arose from the fact that for almost all buildings, the distribution of ease of evacuation ratings was not normally distributed, revealing that participants had no strong consensus about whether a given building was easier or more difficult to evacuate. An example histogram of ratings for one of the buildings is shown in Figure 3. It was particularly interesting to note that this lack of consensus persisted across both architecture and construction engineering students, suggesting that even architecture students do not automatically translate a floorplan to a sense of evacuatability. Based on this result, the authors chose to not use this data to validate the EASE score at this time. Future efforts may validate the EASE score using 3D models of the buildings in which participants evacuate more similarly to a 3D video game.

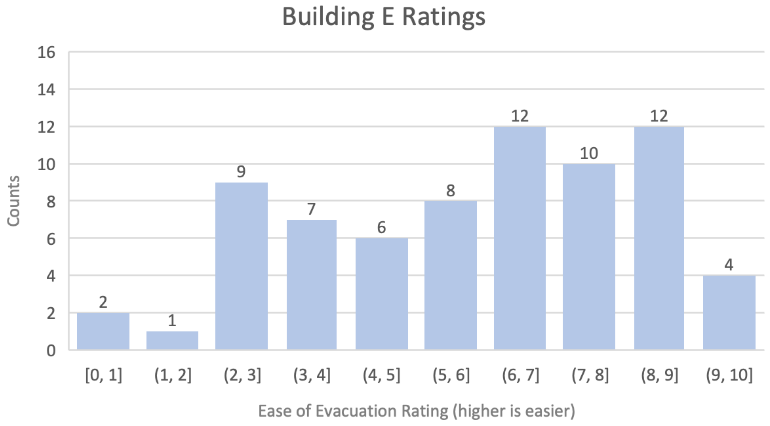

Figure 3: The 71 surveyed participants rated each building floorplan's ease of evacuation on a 0-10 scale where higher was easier. This example from the Building E is similar to the distributions for other buildings, showing there was little consensus. The distributions were not normally distributed.

5 DISCUSSION

While the current EASE score is not yet validated, the results demonstrate that this approach could be useful. Building D, with the lowest EASE score (much lower than the next highest score) is a dormitory with all rooms on a hallway with very close exits. Also, the floorplan has symmetry in two directions, suggesting that even if residents became disoriented during evacuation and forget which hallway they were on, exits would nevertheless be nearby. Building F, with the highest EASE score, is noteworthy because it does not have the greatest square footage, but it does have the greatest number of rooms (agents) and exits (11, far greater than other buildings). Thus, while the square meters per exit is lower, the building is nevertheless difficult to evacuate. Not all exits are equally used, with one of the 11 exits handling 33% of agents. Also, while the IQR of travel time is reasonable (30.0 s), and in range with most other buildings, the maximum travel time (124.0 s) is far larger. A more detailed analysis of evacuation times for Building F showed that 75% of agents had evacuated by 39.0 s, but that a cluster of six other agents required 60.1 s to evacuate, and a second cluster of five agents required the remaining time. The travel times for that second cluster were statistical outliers using the 1.5IRQ calculation, and those agents were deemed "late evacuators." This phenomenon likely results from the higher degree of room nesting that can be seen in Building F (fewer rooms are adjacent to a main hallway).

Buildings C and B have the same EASE score, and it is worth comparing their floorplans to see if this makes sense. Building B is almost twice the size of Building C, but has a much lower IQR for Travel Time and Travel Distance. This situation is a good example of how the metrics chosen for the EASE score reflect aspects of the floorplan layout. Building C is shaped approximately like a plus sign, with exits roughly at the end of each spoke. Thus, any agents in the middle need to travel an entire spoke to exit. It also has rooms of different sizes, leading to more varied travel distances and times. Building B, on the other hand, has most rooms on a hallway, and the exits are at both ends of each hallway, decreasing required travel distance and time. Many rooms are roughly the same size, decreasing variance in travel distance and time. In this way, the EASE score metrics attempt to offer quantitative measures of some aspects of the building floorplans that could possibly be inferred visually, but might be difficult for non-architects.

6 LIMITATIONS AND FUTURE WORK

There are limitations to the BuildingComplexity, both with agent scripting and the handling of the building itself. These limitations are minor and still allow the program to function, but show areas for future improvement. In terms of agents, BuildingComplexity does not consider the variable speeds that humans have when in a stressful emergency situation, and it doesn't consider people who make sure everyone else has vacated an area before leaving themselves. It also does not account for people who attempt to exit using the door they entered, rather than the closest exit. Additional behavioral features like multiple crowd-based effects, individual differences, and random distribution will could be added to BuildingComplexity to increase its predictive capabilities of human behavior for future research.

In terms of building-related factors, stair geometry and corridor width have shown to have a significant impact on evacuation success [24], and could be added to the software. Also, factors such as smoke or occluding debris that could be present in real fire scenarios were not considered in this model. Also, in real buildings, exit signs guide occupants to an exit during times of an emergency, but this model does not include them. Future work plans for BuildingComplexity include updating the modular tool to allow for curved or angled walls or floors, smoke variables, and exit signs. Future work could also allow the user to see visual feedback based on how each individual agent did and based on highlighting any possible problem areas of the building.

Finally, it is worth analyzing the differences between evacuating for fire, in which people avoid proximity to the fire, and evacuating for a shooter, in which people avoid being in line of sight of the shooter (but hiding in nearby room might be fine). Some researchers have begun this sort of comparison [25], but not quite with the same intent as the EASE approach. The EASE score may or may not reflect the safety of building residents during a shooter.

7 SUMMARY

The aim of this study was to introduce BuildingComplexity, an open-source Unity software application designed to assess building evacuation ease through agent-based modeling. The authors proposed metrics for evaluation of a building's ease of evacuation: the EASE score, which combines multiple metrics related to code compliance, path simplicity, exit availability, total travel, and congestion that were calculated from agent-based simulation. Results presented seven buildings modeled using BuildingComplexity, generating EASE scores for comparison. Future validation may conduct a factor analysis of the EASE score metrics to calculate whether any metrics in the score might be redundant or not properly weighted. Additionally, an attempt at EASE score validation through human surveys revealed participants' challenges in interpretating of floor plans consistently. Future human-based validation efforts may involve 3D models for more realistic evacuation scenarios.

BuildingComplexity offers an agile, iterative alternative for assessing evacuation ease, emphasizing quick and easy usability. While acknowledging the challenges and limitations, the tool provides a valuable contribution to building design evaluation and emergency planning, striving to enhance human safety during evacuations.

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