KTH ROYAL INSTITUTE
OF TECHNOLOGY

DEGREE PROJECT IN COMPUTER SCIENCE AND ENGINEERING

FIRST CYCLE, 15 CREDITS

Evaluating impact of table layout in classroom evacuation with crowd simulation

SANJIN REDZEPAGIC

ALEXANDER GUSTAVSSON

Stockholm, Sweden 2022

Evaluating impact of table layout in classroom evacuation with crowd simulation

SANJIN REDZEPAGIC

ALEXANDER GUSTAVSSON

Degree Project in Computer Science and Engineering
Date: June 7, 2022
Supervisor: Christopher Peters
Examiner: Jörg Conradt
School of Electrical Engineering and Computer Science
Swedish title: Evaluering av inverkan av bordsplacering på klassrumsevakuering med simulering av folkmassor

Abstract

With the rise of hazardous events in classroom and school settings, the need for efficient and safe evacuation planning has never been more vital. Relying on intuition to draw conclusions, while often well intended, can do more harm than good. Previous studies into human behavior during emergency evacuations show that ineffective evacuation processes can lead to injuries, and even prove to be fatal, themselves. Most research into the area of evaluating the efficiency of certain evacuation processes focuses on one metric, the total time it takes for the room population to evacuate the room. This study shows that while it is a critical metric, there are other metrics that could, and maybe should, be taken into consideration.

This thesis studies the effects certain table layouts have on the time it takes for people to evacuate a room using advanced crowd simulation. The simulation system builds upon treating the crowd as a unilaterally incompressible fluid. The digital environment is modeled after a classroom at KTH Royal Institute of Technology. The two key factors studied are the amount of paths to the exit available to the evacuees, and the evacuation time of percentages of the room population.

The results indicate that the amount of paths available to the evacuees does not impact the average total evacuation time. They do, however, show that certain layouts can lead to faster evacuation times but less consistently, while others can lead to slower evacuation times but more consistently. They also show that while certain layouts may yield faster total evacuation times, the time it takes for different percentages of the total room population to evacuate can be considerably slower than other layouts that have slower total evacuation times. While this does bring great moral and ethical implications with it that cannot, and should not, be avoided - when it comes to studies into saving lives, everything needs to be considered.

Sammanfattning

Med den ökade frekvensen av farliga händelser i klassrum och i generella skolmiljöer, har behovet för effektiv och säker nödutrymmningsplanering aldrig varit större. Att förlita sig på personlig intuition, trots all välmening, för att dra slutsatser kan göra mer skada än gott. Tidigare studier inom mänsklig beteende under nödutrymningar visar att ineffektiva utrymningsprocesser själva kan leda till allvarliga skador, eller i värsta fall döden. De flesta studier som undersöker hur effektiva diverse utrymningsprocesser är fokuserar ofta endast på ett mått, den totala tiden det tar för alla i rummet att evakuera rummet. Denna studie visar att, även om det är ett kritiskt mått, finns det även andra mått som skulle kunna, och kanske bör, också beaktas.

Denna avhandling studerar effekten vissa bordskonfigurationer har på tiden det tar för folk att evakuera ett rum med hjälp av avancerad simulering av folkmassor. Simulationssystemet bygger på principen att behandla folkmassor som en ensidigt inkompressibel vätska. Den digitala miljön är modellerad efter ett klassrum i KTH Kungliga Tekniska Högskolan. De två främst studerade nyckelfaktorerna är; antalet vägar till utgången, samt utrymningsstiden för andelar av personerna i rummet.

Resultaten indikerar att antalet vägar som finns tillgängliga för personerna har ingen inverkan på snitttiden det tar för alla att evakuera rummet. Däremot visar de att vissa bordskonfigurationer kan leda till snabbare, men mindre konsekventa utrymningstider, medan andra kan leda till långsammare, men mer konsekventa utrymningstider. De visar även att trots att vissa bordskonfigurationer kan leda till snabbare utrymningstider totalt, kan tiden det tar för olika andelar av personerna i rummet att evakuera vara betydligt långsammare än för andra bordskonfigurationer med långsammare totala utrymingstider. Även om detta för med sig stora moraliska och etiska implikationer som inte kan, och inte bör, ignoreras - när det kommer till studier om att rädda liv måste allt övervägas.

Contents

1 Introduction

A steadily growing population means steadily growing cities, and with it, a lot of new construction. An important aspect when designing new buildings is planning efficient and well-designed evacuation routes, and sometimes even prioritizing having efficient evacuation routes over other aspects like utility or aesthetics.

The primary focus when studying or designing efficient evacuation routes is typically on the exits themselves; location, width, number of exits etc., but there could be other factors worth taking into consideration. One such factor is to look at the furniture layout in the rooms, and how their placement affects the evacuation time of the room. This is especially relevant in rooms which generally need to have dense usage of furniture such as study halls, libraries, lecture halls and classrooms. In a previous study done by Willy Liu and Daniel Parhizgar, they focused on the exits, and how they impacted evacuation times. They concluded however that the table layout in a classroom could potentially have a bigger impact on the evacuation time rather than the layout of the exits in the room, but that further research was necessary [1].

However, predicting how people will react in emergency situations can be very challenging [2], and in some cases can lead to injuries and even death due to stampedes as the crowd races towards the exits [3]. It is not only difficult to simulate panicked behavior accurately, but also the level of panic of individuals in the crowd. Previous research has shown that panicked individuals in crowds can cause widespread defection and panic which then slows down the overall evacuation time. The evacuation time subsequently also increases with higher panic levels [4].

Although accurately simulating these emergency situations in digital environments can prove to be challenging due to the complex nature of human behavior, it can still help to visualize the flow of room occupants and can illuminate crucial flaws in the design and layout of the room and save lives.

1.1 Research question

In a previous study done by Willy Liu and Daniel Parhizgar, they found that the table layout in a classroom could potentially have a bigger impact on the evacuation time rather than the layout of the exits in the room, but that further research was necessary [1]. Research and studies into the impact of table layout in classrooms is scarce. This study explores the impact of the placement and layout of the tables in classrooms on the evacuation time using crowd simulation. Specifically how the table layouts affect the possible paths towards the exit. The digital environment is modeled after one of KTH's classrooms, namely E31. More research into this area can potentially highlight dangers in current classroom designs and present improvements that can be made in classrooms at KTH.

The study uses advanced crowd simulation to place agents, which are digital representations of people, in digital classroom environments and have them move towards the exit. This simulation is then run using four different table layouts and the findings are then analyzed. Two of the layouts are frequently occurring in the classrooms at KTH, where one is the standard layout for classroom E31. The other two layouts are based on layouts from Yale [5]. More about the layouts can be found in 3.3.1. The layouts are also chosen to have a range of different amount of table groups, as in tables pushed together. This is so that the different scenarios would include different amount of paths towards the exit. Less individual tables and more larger table groups mean less options for paths.

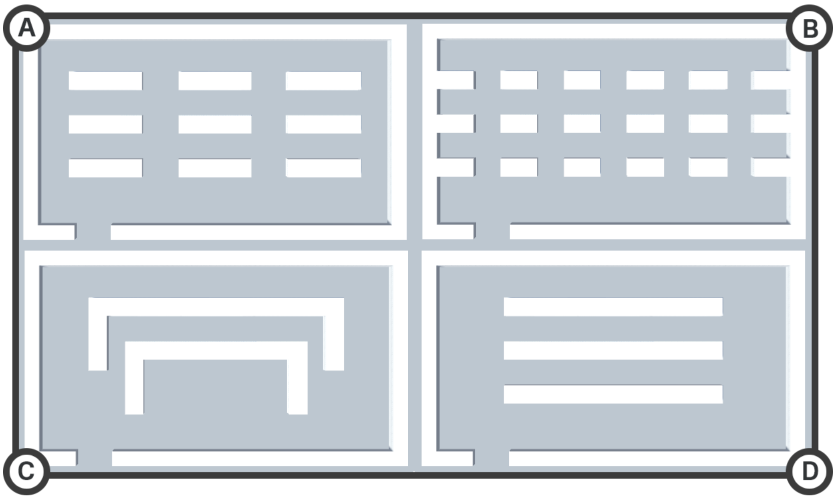

Figure 1.1: The four table layouts used in this study.

Our primary research question is formulated as follows:

How does the evacuation time of a classroom at KTH differ given a set of paths created by various, predetermined, table layouts?

The study further aims to break down the primary research question into these two research questions and answer them:

RQ1: *How does the amount of possible paths towards the exit affect evacua-*

tion time?

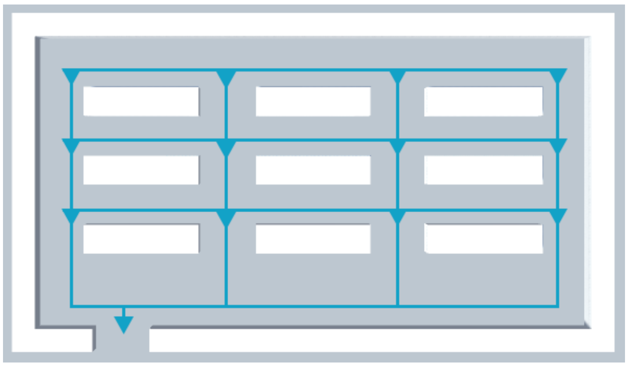

Figure 1.2: The amount of table groups affects the amount of paths available towards the exit.

If we assume only lateral and southward movement (by the orientation seen in figure 1.2), and that agents cannot walk the same line twice; we see a direct relation between amount of table groups and amount of paths towards the exit. more individual tables mean more possible paths to the exit because the scattered tables create a grid of paths. This is interesting to look at because it is not inherently intuitive whether more options means faster evacuation. As visible in figure 1.1, three of the four layouts have all their tables set up in three rows, with the rows being in the same position on the Y-axis in all of them. The only difference being the amount of individual table groups, as in tables pushed together to form one larger group. This ensures that any differences in the results between these layouts will be limited to the amount of paths available. Analysis and discussion about RQ1 can be found in 5.1.1.

RQ2: *How do different table layouts affect the evacuation time of percentages of the starting room population.*

The time it takes for every room occupant to evacuate is commonly the most looked at metric in evacuation research, however there could be interesting results to be found in looking at the partial evacuation times. In scenarios where none of the layout options yield fast enough total evacuation time for certain emergencies, layouts with slower total evacuation times could be interesting to look at if their partial evacuation times are faster than others. This idea does however bring with it great ethical and moral implications.

Analysis and discussion about RQ2 can be found in 5.1.2.

1.2 Scope

The scope of the paper focuses on having the crowd simulation yield valuable information in regards to evacuation time, at the expense of realism and implementation of complex human behavior. Attempting to emulate complex human behavior excessively could lead to inaccurate simulations and is out of the scope for this thesis. All table layouts will always use thirtysix(36) agents and eighteen(18) tables to ensure consistency.

The crowd simulation implementation this study uses is based on Jack Shabo's particle based crowd simulation work for his thesis at KTH [6] which in turn is based on Narain et al.'s *Unilateral incompressibility constraint simulation* [7].

Other delimitations include:

- The simulation only considers door(s) as evacuation points, windows and other points of exits are not considered.
- Type of emergency is not considered. Simulating behavior based on the type of emergency such as fire, violence, earthquake etc. is out of the scope for this thesis.
- Chairs are not considered. Including chairs in the simulation accurately would increase the complexity of the simulation enormously. Attempting to do so could even lead to unknowingly implementing inaccurate behavior that skew the results dishonestly.
- The environment is modeled after classroom E31 at KTH Royal Institute of Technology to ensure that the results are more applicable to the real world.
- Panic and human senses are not considered. While these are important factors, attempting to emulate human behavior in emergency situations can be very challenging [2] and could lead to dishonest and unverifiable results.

1.3 Outline

Chapter 2 introduces the necessary context and background to the study. Concepts of interest include crowd simulation and crowd behavior in evacuation simulations. The chapter also describes other necessary aspects such as primary software used and relevant algorithms.

Chapter 3 describes the implementation used to answer the research question and how data is collected and evaluated.

Chapter 4 presents the detailed results and data in the study with relevant figures and graphs.

Chapter 5 contains discussion and analysis of the results and data collected.

Chapter 6 presents a final summary of the relevant, and most important findings, in the conclusion of the study.

2 Background

2.1 Crowd simulation

The concept of simulating crowds in digital environments realistically has long been a coveted achievement [8]. It is a concept that is applied to several areas in modern society. The movie industry uses crowd simulation to avoid the need to have large amounts of actors to fill out arenas, audiences, marches, battlefields etc. The video game industry uses it to achieve greater immersion for the user, e.g. when navigating in a city.

Figure 2.1: Crowd simulation used in the movie World War Z (2013) to simulate zombies.

It is also heavily used in research and other scientific areas where important and interesting information can be found by simulating certain real-life scenarios. This paper focuses on the latter, by simulating emergency situations in a classroom environment to evaluate the effect the table layout has in said classroom on the evacuation time.

When designing a crowd simulation, realistic behavior is ideally the goal. However, it is exceedingly hard to accurately emulate human behavior digitally because of the inherent unpredictability in humans [2]. Due to this, there are different ways to simulate crowds, all with their use cases, depending on the primary priorities of the project and the crowd size [9][10].

This study uses crowd simulation to simulate the evacuation process to get tangible data on how the paths created by various table layouts affect the evacuation time. The crowd simulation implementation used in this study uses the UIC algorithm developed by Narain et al. [7], which will be discussed in the next section.

2.1.1 Unilaterally incompressible fluid

When dealing with single, or few agents, implementation of individual behavioral properties is an option. However, when dealing with crowds, many scenarios require rather large and dense crowds which can often be very computationally demanding [11]. This is because agents will not inherently avoid each other unless explicitly told to do so on an individual level, which requires a considerable amount of computations to be done for every agent in the simulation.

This study uses a simulation method that is based on the algorithms created by Narain et al. [7], which was introduced to handle this problem and is highly optimized for large crowd sizes. Large dense crowds of people can be seen to deviate from individual behavior and instead move as a collective, almost like a fluid [12]. The method introduced by Narain et al. to simulate crowds as unilaterally incompressible fluids, builds upon these observations of human behavior in crowds, and treats the crowd as one collective rather than individuals. The premise of the system is to treat agents as incompressible particles which means that they cannot occupy the same space at the same time. It uses a grid system of cells to calculate the mean velocity of the agents in the cell and then apply that to all the agents inside the cell while also avoiding local collisions.

This algorithm, and the method of simulating crowds with it, is relatively new, so further research into the area is useful. The specific crowd simulator, which runs in realtime, used in this study was created and implemented by Berglund and Ristic [13] and further developed by Jack Shabo [6] in Unity; which will be discussed in the next section.

2.2 Unity

The environment used to simulate and evaluate was Unity3D. It is a highly versatile game engine that has gradually extended to support a variety of desktop, mobile, console and virtual reality platforms. It is primarily for game development but Unity can also be used for interactive simulations and other experiences which is what it is used for in this study. The crowd simulator, developed by previous students [13] [6], used in this study was also designed in Unity, and runs in realtime, which makes the decision to also use Unity evident. Unity provides easy ways to design and alter shapes and environments and allows for implementing scripts in C.

2.3 Previous Work

Simulating crowd evacuation is a well researched area. Research into room evacuation, however, often focuses on the exits and less on various layouts of the furnishing. This study primarily builds upon the work of Liu and Parhizgar [1], which studied the impact of having more exits, and the width of the exits, had on total evacuation time. They concluded that based on their results, the furnishings, such as tables and chairs, had a larger impact on the evacuation time than the exits, but that more research was needed on the topic.

2.3.1 Approach

In their study, they evaluated how the evacuation time of a room in an emergency was impacted by the number of exits available and the width of the exits. Their predefined scenarios were as follows:

- One door (1 door)
- Two doors along the same wall (2 doors)
- Three doors along the same wall (3 doors)
- One door at the back of the classroom (1 door back)
- One double door at the back of the classroom (double door)

They modeled their digital environment after three different sized classrooms at KTH and used a modified version of Berglund's and Ristic's *UIC* implementation [13] by Jack Shabo [6], which incorporates an adapted version of Floyd-Warshall's algorithm to calculate the shortest path, to simulate the crowd evacuating from the classrooms.

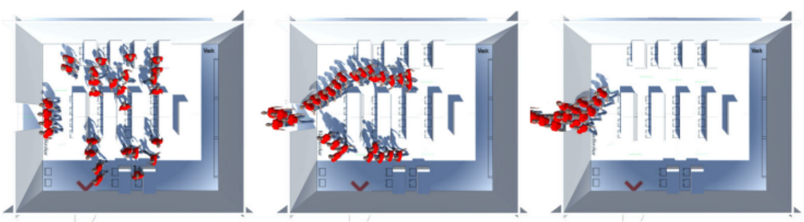

Figure 2.2: Evacuation process in Liu's and Parhizgar's system, one door in the back. Small classroom.

2.3.2 Findings

They ran the simulation five times for each of the scenarios and calculated the average evacuation time for each. They also included the standard deviation for each. What their results showed was that the improvement in evacuation time had diminishing returns in terms of adding more exits, the greatest improvement was going from one exit to two exits.

The medium classroom showed some deviation from the pattern they saw in the other classrooms. In the other two classrooms, the double door scenario was among the slowest in terms of evacuation time, however in the medium, it was the fastest. They concluded that this phenomenon was unlikely to be due to chance, but instead was more likely to have occurred because of the table configuration in said classroom. They came to this conclusion by looking at the evacuation process and noticing that there were three lanes being formed, in contrast to the other classrooms where there were only two, due to the placement of the tables.

Our study continues on this hypothesis by Liu and Parhizgar and tries to evaluate how various table layouts affect the evacuation time. Specifically it looks at how the paths created by various table layouts affect the evacuation time of the room.

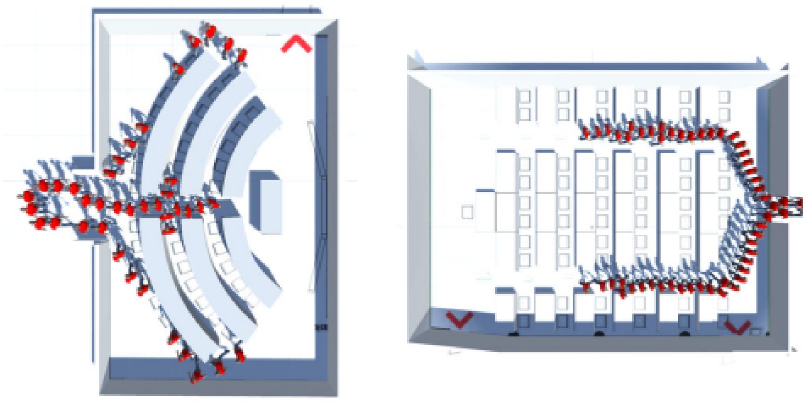

Figure 2.3: Evacuation process in Liu's and Parhizgar's system with Three lanes vs. Two lanes

3 Method

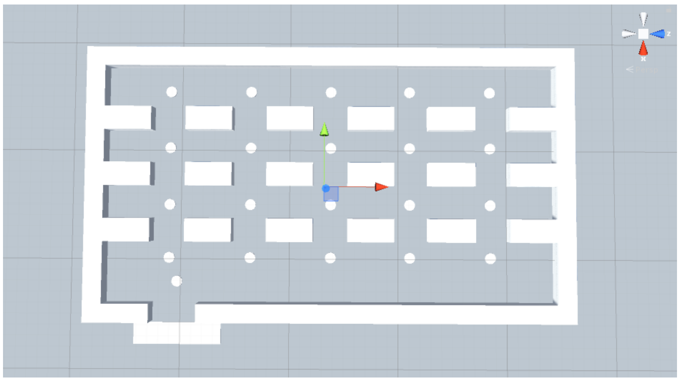

Figure 3.1: Scene view of layout B in the simulator showing the nodes (circles) needed for the agents to calculate their path.

This study used advanced crowd simulation to place agents in digital classroom environments, and then had them evacuate the room as we recorded the process and time. The realtime crowd simulation implementation used in this study is a variant developed by previous student Jack Shabo [6] in Unity. The system is based on the UIC algorithm by Narain et al. [7] which is a relatively new way to simulate crowds as unilaterally incompressible fluids (more can be read about this in 2.1.1). The digital classroom used in this study is based on classroom E31 at KTH Royal Institute of Technology, and features four different table layouts. The simulation environment was built, and run, using Unity (read more about Unity in 2.2). The crowd simulator used nodes, placed around the classroom, to allow the agents to form a path around the tables towards the exit.

The evaluation focuses on total and partial evacuation. The former meaning the time it takes for all room occupants to evacuate, and the latter meaning the time it takes for parts of the room population to evacuate. It also strives to examine how the number of possible paths towards the exit affect the evacuation time.

3.1 Crowd simulator

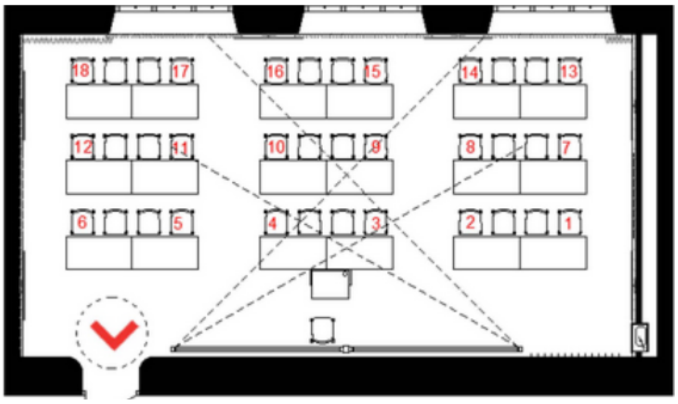

Figure 3.2: Blueprint of classroom E31 with the standard table layout.

This study used a realtime crowd simulation method originally implemented by Berglund and Ristic [13], and further developed by Jack Shabo [6]. It was not originally intended for simulating emergency evacuations although it does lend itself well to the cause due to how well it simulates crow behavior. The crowd simulator is based on the work of Narain et al. [7] where they developed an algorithm that treats crowds as unilaterally incompressible fluids. This method allows for simulations to use large and dense crowds without the need for substantial computational power by treating crowds as one collective rather than individuals (more about this can be read under 2.1.1). While the crowd simulator used, does simulate calm crowd behavior well, it does lack the panicked and individual behavior that is usually present in emergency situations. It is, however, challenging to simulate a lot of the typical human behavioral traits such as panic and sense, and using crowd simulation for this study was the most effective method because of its low cost and flexible usage. Developing a custom crowd simulator from scratch for this study would have been too complex and time consuming and is out of the scope for this thesis. There is however much that can be learned about evacuation processes without implementing panicked behavior. Due to this, the crowd simulator variant by Shabo [6] was the ideal choice.

3.2 Creating the scenarios

The study simulated the evacuation process of a crowd in a classroom in order to examine how the paths created by the table layout in the room affected the evacuation time. The classroom environment used in the simulation is entirely based on classroom blueprints from KTH Royal Institute of Technology, specifically in this study; classroom E31. The simulation and the environment was built in Unity version 5.6.0 (more about Unity in 2.2).

KTH provides blueprints and other information regarding all their classrooms and lecture halls online. These blueprints were used to model the environment digitally in 3D to ensure accurate representations of real classrooms. This aids the study to have real world implications. Using Unity for the study allowed us to change the table layout with ease.

The study included four different table layouts (which are presented under 3.3.1) but the amount of agents and tables remained the same; 36 agents and 18 tables. This decision was made to limit the number of factors that could affect evacuation time other than table layout.

For the simulation to be effective, the agents needed three kinds of nodes in the environment, spawn nodes for their starting positions, regular nodes to create straight paths without interference, and a goal node for them to ultimately aim to reach. The spawn nodes were placed by the tables based on seating arrangements. The goal node was placed in the simulation where the exit is located on the classroom blueprint. The regular nodes were placed around the classroom to allow the agents to walk around the tables. It was vital for the agents to be able to see the nodes without any objects in between, such as tables, for them to be able to progress.

With the use of the regular nodes and the goal node, the simulator allowed the agents to calculate the shortest path using an adapted version of Floyd-Warshall's algorithm [6]. Once an agent moved into the goal area they were removed in order to not block the other agents from reaching the goal.

The simulations did not handle collision detection between room occupants and tables. The tables did however obstruct the room occupants' line of sight which meant that the room occupants could only reach nodes they could directly see. The room occupants were also restricted by the UIC algorithm, which does not let them walk through each other. These two factors governing the simulation yielded good results, forcing the room occupants to still adhere to the paths created by the table layouts.

3.3 Room layouts

To get results that were applicable and verifiable in real life, we used floor plans from KTH Royal Institute of Technology's website of E31 to both model the environment and determine the number of agents and tables in the classroom (see 3.3.1 for the table layouts). We used existing floor plans for classrooms at KTH Royal Institute of Technology for the table layouts A and B. Table layouts C and D were based on examples from Yale[5]. The dimensions of the tables used are equivalent to the tables found in E31 at

KTH Royal Institute of Technology. Due to this, and the restriction of using specifically 18 tables and 36 agents, table layout C and D may vary a little from the examples from Yale.

The room layouts were also chosen to have varying amounts of possible paths towards the exit. While every layout used the same amount of tables, we could still achieve this by rearranging multiple individual tables into larger table groups. More individual table groups meant more possible paths available as the agents traversed across the room. It was also important that the tables that were oriented horizontally did not vary in their location vertically in the room. E.g. layouts A,B and D in the figures below, all have three rows. All three rows are in the same position vertically in the room. Layout C only has two rows, and not all the tables are horizontally oriented. However, the tables that are horizontally oriented in layout C are also in the same position vertically as the top two rows in the other layouts. This decision was made to ensure consistency between layouts.

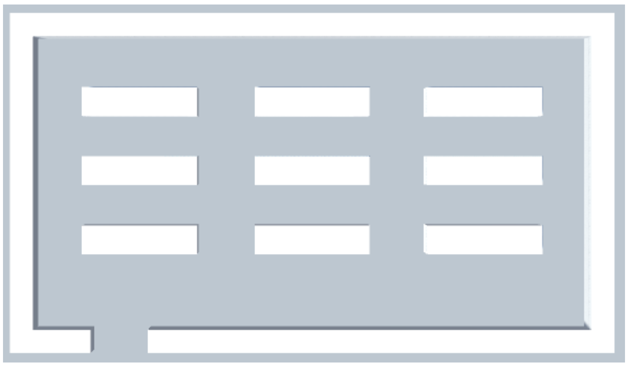

Figure 3.3: Table Layout **A**. The standard table layout for E31 per the classrooms blueprints. Note that two tables have been put together to form each group.

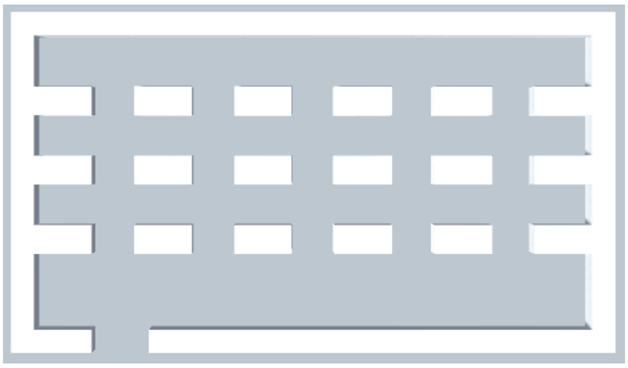

Figure 3.4: Table Layout **B**. Frequently used in the classrooms at KTH. Features the most possible paths towards the exit.

Figure 3.5: Table Layout **C**. Based on the *Double Horseshoe* layout from Yale[5], adapted to fit the restrictions in this study. Features the fewest possible paths.

Figure 3.6: Table Layout **D**. Based on the *Traditional* layout from Yale[5].

3.4 Evaluation

The primary data collected in other studies such as Liu's and Parhizgar's focus on solely recording the time it takes until total evacuation occurs. While it isn't surprising that this point of data is most often prioritized, we believed that there was value in also knowing the time it took for parts of the group of evacuees to evacuate. This is because certain layouts may allow for very quick evacuation from some areas in the room, leaving only a few who take longer. This may yield an overall slower evacuation time, while other layouts can be faster overall but have more of the evacuees leaving the room near the end of the time frame. This is interesting in cases of emergencies that are rapidly spreading and where quick evacuation is crucial such as fires, where potentially neither layout is fast enough for all evacuees to evacuate. It might be worth considering a layout where a larger fraction of them do, even if the total time is slower. This does however pose serious moral and ethical implications, which we will discuss more in 5.2.

The study also evaluated the effect the number of paths had on the evacuation time of the room. While we used the same amount of tables in each scenario, by rearranging multiple individual tables into larger table groups, we could have varying amount of paths available. See RQ1 in 1.1 for more on this.

A simple script was created for recording the evacuation time. A timer was started when the agents began to move. The timer was then stopped once the last agent reached the exit. The time was also registered when 20%, 40%, 60% and 80% of the total classroom population, rounded down, had evacuated. This process was repeated five times for every table layout used in the classroom simulation as to get more reliable results. The average times, and the standard deviations, were then calculated from the data gathered and the resulting data was used to draw conclusions and answer our research questions.

4 Results

The results of the simulations will be presented in this chapter. Four table configurations were used, as presented in 3.3.1, and the results are presented in two sections. The first looks at the total evacuation time for all room occupants for all table configurations. The second will look at the partial evacuation times for 20%, 40%, 60% and 80% of the room occupants to evacuate the classroom. The sections look at the relative variations between each layout and present them in tables and graphs along with example snapshots from the evacuation process.

The time did not vary significantly between runs of the simulation with the same table layout so it was deemed that 5 simulations per table layout was enough data to calculate an average evacuation time for the measured population percentages. Note that it is not the absolute value of the results that is relevant, but the relative difference between the findings.

4.1 Total evacuation

The total evacuation time refers to the time it takes for all room occupants to evacuate the classroom. Figure 4.1 shows an example of an evacuation process with table layout C.

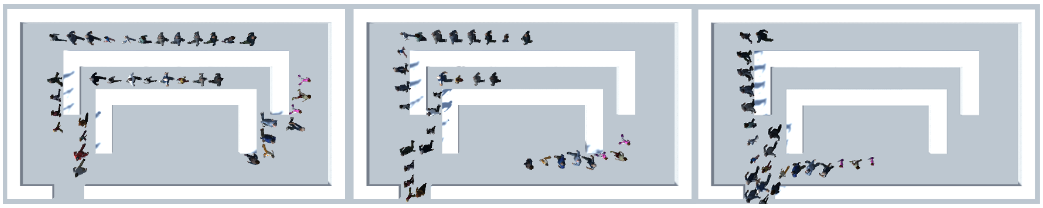

Figure 4.1: Evacuation process with table layout C. It has the fewest possible paths out of the four layouts.

Table Layout	Run 1	Run 2	Run 3	Run 4	Run 5	Avg.	Std. Dev.
A	14.790	14.797	14.808	14.804	14.820	14.804	0.011
B	16.277	16.283	16.277	16.273	16.268	16.276	0.005
C	16.836	16.826	16.826	16.830	16.907	16.845	0.035
D	15.964	15.925	15.934	15.932	15.946	15.940	0.015

Figure 4.2: Evacuation times for each table layout for total evacuation.

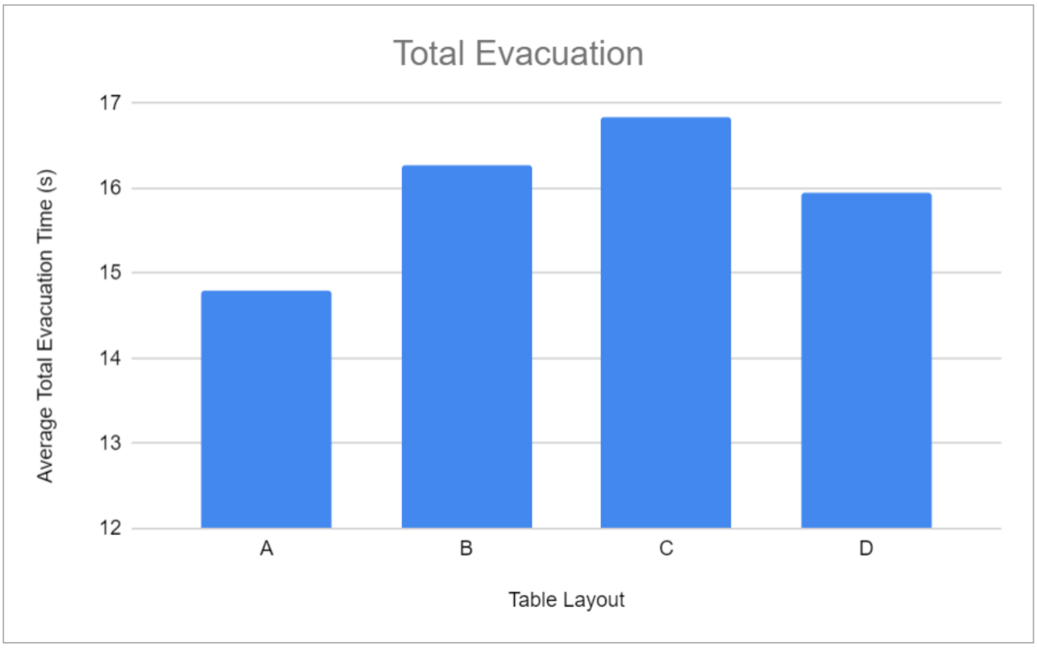

Figure 4.3: Graph showing the average evacuation times between layouts.

Figure 4.2 shows that the standard layout for classroom E31, layout A, yields the fastest total evacuation time, over a second quicker than layout D. The evacuation times overall are relatively similar though.

4.2 Partial evacuation

Partial evacuation time refers to the time it takes to evacuate 20%, 40%, 60%, 80% of the classroom occupants. Total evacuation, 100%, will also be presented along with the partial evacuation times for comparison. Only the average evacuation time will be presented for each interval for readabilities sake.

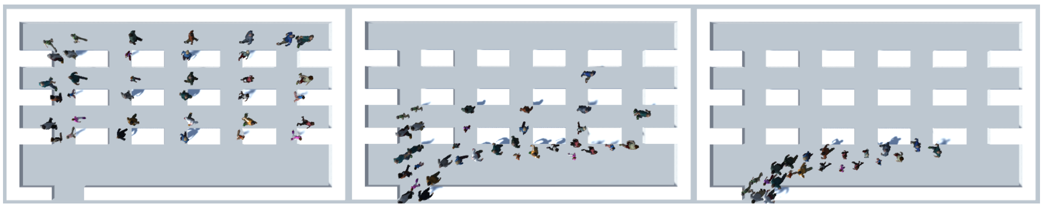

Figure 4.4: Evacuation process with table layout B. It has the most possible paths out of the four layouts.

Table Layout	20%	40%	60%	80%	100%
A	6.765	8.831	10.468	12.400	14.804
B	6.016	7.800	10.038	12.732	16.276
C	5.926	9.379	11.405	13.316	16.845
D	7.191	9.188	11.239	13.314	15.940

Figure 4.5: Evacuation times for each table layout for partial evacuation.

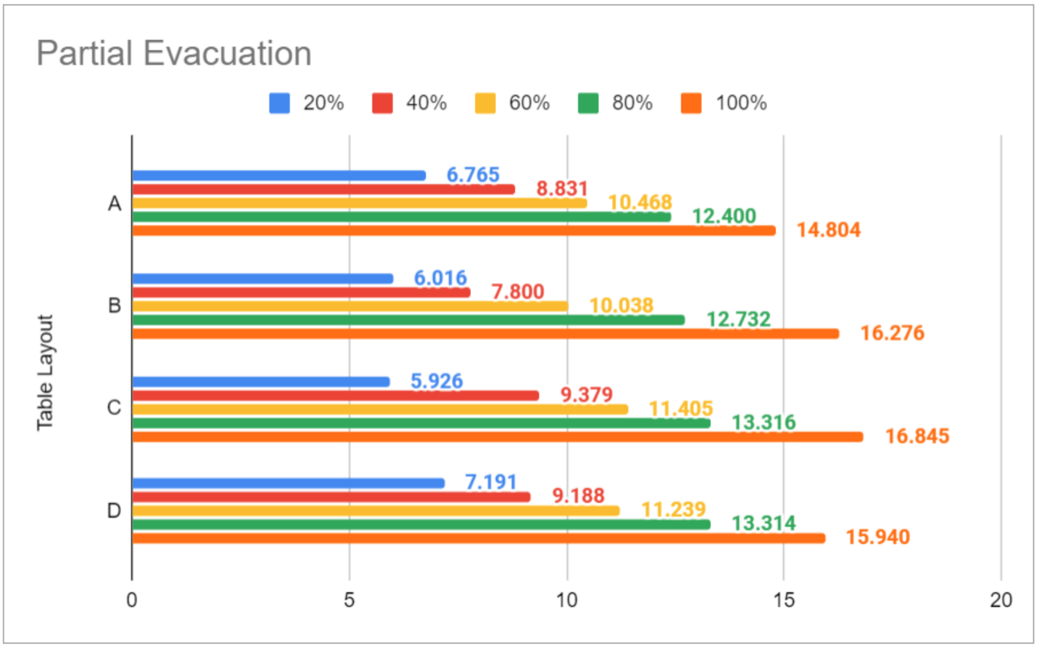

Figure 4.6: Graph showing that the evacuation time does not increase equally between layouts. Slower total evacuation time can still have faster partial evacuation times.

Figure 4.6 shows that while layout C yields the slowest total evacuation time, it has the quickest partial evacuation time for 20% of the room occupants. Layout B, which yields the second slowest total evacuation time, yields faster partial evacuation times than Layout A up to, and including, 60% of the room occupants.

5 Discussion

This chapter discusses the findings, provides an analysis of them, and aims to answer the research questions. It also includes thoughts around how the study could be further improved to not only yield more accurate results, but also results that could be useful to evaluate other areas not touched upon in this study. Lastly it discusses the ethical and moral implications of the study.

5.1 Research question

The digital environment was modeled after the actual classroom, E31, at KTH. Four table layouts, using 18 tables and 36 agents, were chosen to be put through a simulation of an evacuation process. Two of the layouts were commonly found ones in the classrooms at KTH, and the other two were suggested ones from Yale [5]. All four of the layouts were chosen so that they would include different amount of paths towards the exit.

The results showed that the standard classroom layout used today in classroom E31, named Layout A in this study, yielded the fastest total evacuation time (as can be seen in figure 4.2). The total evacuation time for Layout A was over a second faster than the second fastest, Layout D. This is the largest margin between any two subsequent layouts.

Liu and Parhizgar suggested that the table layout in a classroom could have a greater impact on the evacuation time of that room, than the amount and placement of doors [1]. While the results of this study show that the table layout of a classroom does have a relatively significant impact on the evacuation time, the differences between the layouts are not quite so large that a definitive conclusion can be drawn about their hypothesis.

It is important to note however that the absolute values of these results are not themselves relevant, but only the relative difference between them. This is important because simulating complex human behavior can be very challenging [2]. Attempting to do so could lead to unknowingly implementing incorrect behavior that skews the results incorrectly and was for that reason out of the scope for this thesis. It does however mean that the fundamental aspects that makes us human, like sense and intuition, are not included in the equation. This means that the agents behave in an exceedingly organized and calm way. This behavior means that the agents' behavior is more deterministic and less volatile. In a real world scenario, people can be unpredictable, possibly even completely nondeterministic [14]. Because of this, differences in the environment, such as the table layout, could have considerably larger effects on the evacuation time than measured in simulations. In a real world scenario a certain bottleneck in the path could be the catalyst to people climbing over each other. Whereas in a simulation that does not accurately implement this behavior, the agents could calmly pass through.

5.1.1 RQ1: Number of paths

Layout A yielded the fastest total evacuation time, which can be seen in figure 4.2. If we assume, however, only lateral and southward movement (with the exit being to the south in the depictions of the layouts as seen in figure 5.1), and that the agents never walk the same line twice, layout A has neither the fewest, nor the most, possible paths to the exit. As can be seen in figure 5.1, layout C has the fewest possible paths and layout B has the most.

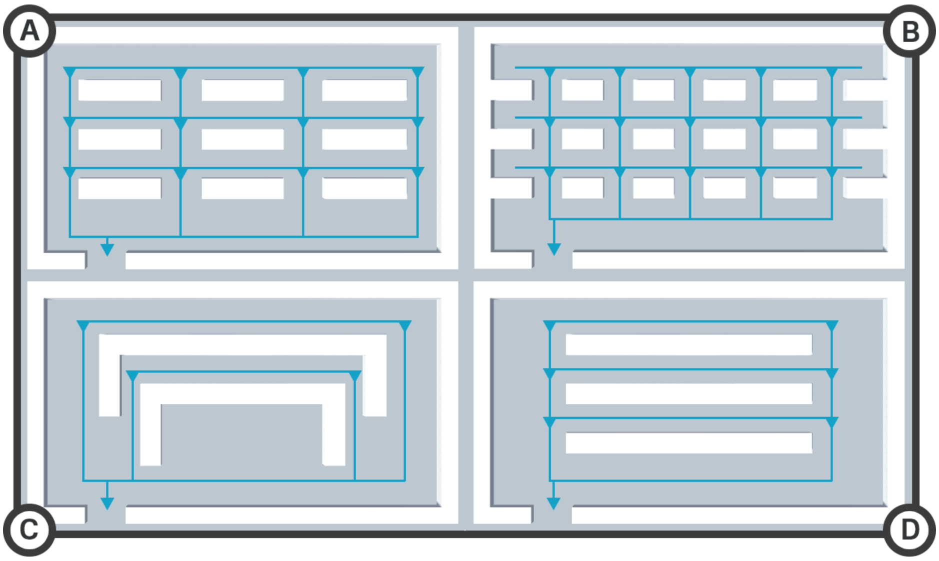

Figure 5.1: Possible paths assuming only lateral, and southward, movement. Layout B has the most, layout C has the fewest.

Layout C has two tables rotated at the ends of each of the two groups which the other two layouts do not have. This can make the results harder to interpret in regards to possible paths having an effect on the evacuation time. The other three layouts, however, all have three rows of tables each. Each row is also on the exact same vertical position in the classroom, meaning that these three only differ in the amount of individual table groups, as in tables pushed together. Layout A has 9 table groups, layout B has 18, and layout D has 3. This means that the only differentiating factor in these three layouts is the amount of possible paths the agents can take. The findings do not change, however, because even without layout C, layout D still has fewer paths than layout A. The results mean that we, unfortunately, cannot draw any conclusions as to whether it is better to have fewer or more possible paths towards the exit.

There is something interesting to note, however, when looking at the standard deviation in the total evacuation times. Due to not implementing some of the complex human traits like sense and panic, the simulations ran in a relatively deterministic manner. This means that the evacuation time between each run did not vary to a great extent. As we have stated earlier in the study though, the absolute values of these tests are not themselves relevant. It is the relative difference between them that are of interest. Figure 5.2 shows that there seems to be a strong connection between the number of table groups and the variance between runs. This indicates that certain behavior that arises between layouts, lead to more consistent evacuations. As stated earlier in 1.2, more table groups, mean more possible paths towards the exit. This means that figure 5.2 indicates that having more table groups lead to behaviors that yield more consistent evacuation times.

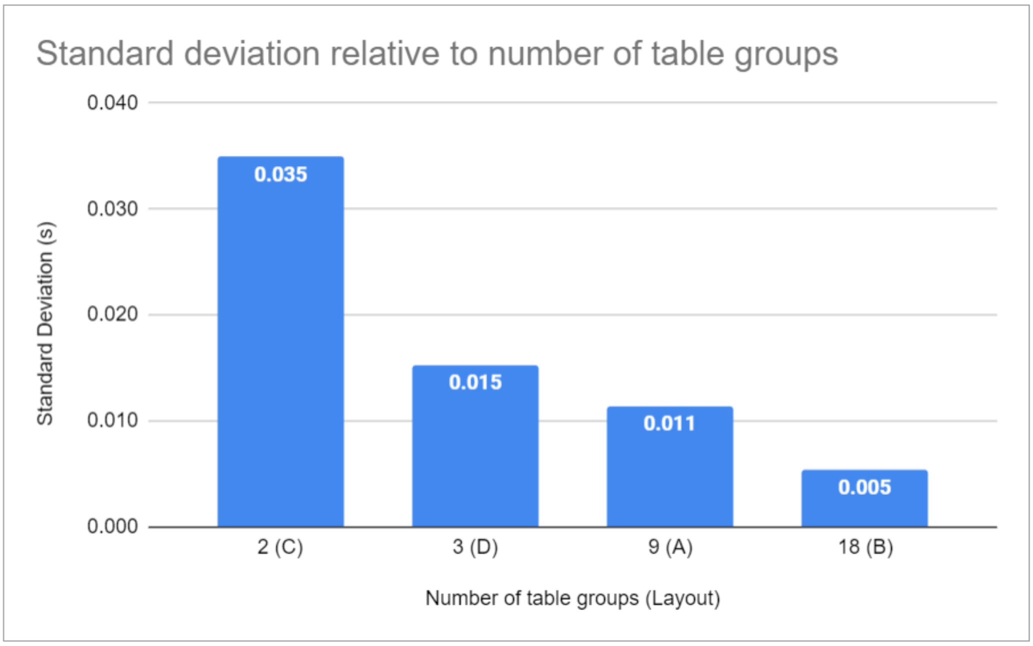

Figure 5.2: Graph showing a clear tendency that layouts with more table groups have less variance in their evacuation times.

What the implications of this is in real world scenarios is unclear and further testing would need to be done to draw any strong conclusions, but it seems possible that it could be a good indicator for how reliable and consistent a simulation of an evacuation is. It may also be an indicator for how susceptible a layout, or evacuation plan, is to obstructions. A large variance could indicate that there is greater room for deviations in the evacuation process.

5.1.2 RQ2: Table layout effect on partial evacuation

As can be seen in figure 5.3, the results show that the evacuation time of percentages of the room population between the four layouts does not increase equally during the course of the simulation. In fact, table layout C yielded the slowest total evacuation time out of the four layouts, and yet it yielded the fastest evacuation time for the first 20% of the room population. Similarly, table layout B, which yielded the second slowest total evacuation time, yielded the fastest evacuation time for the first 60% of the room population.

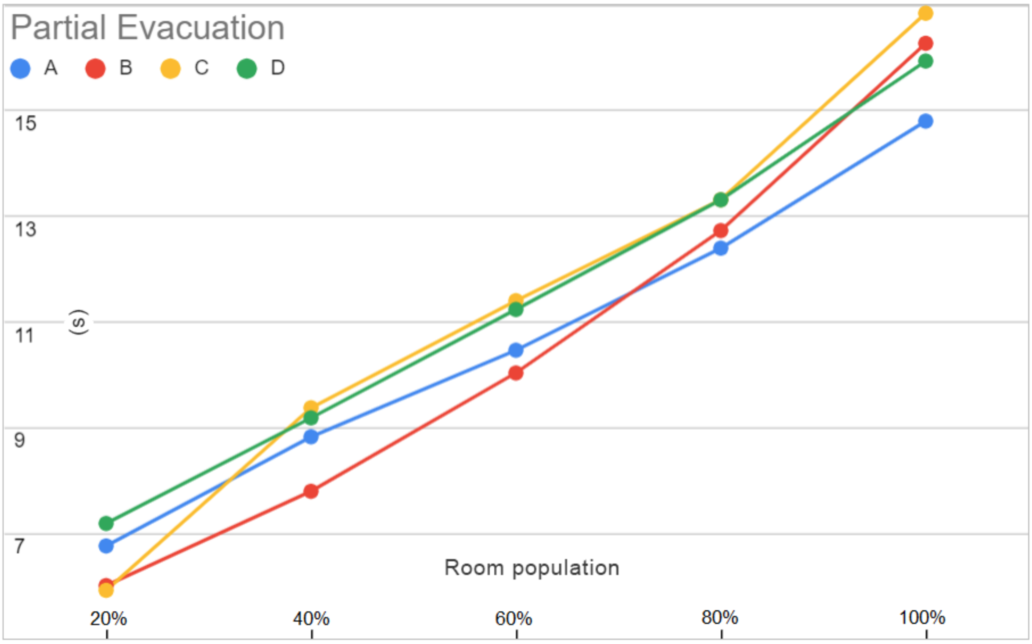

Figure 5.3: Graph showing that layouts with faster evacuation times can have slower partial evacuation times.

Most research into evacuation times using crowd simulation primarily focuses on total evacuation, meaning the time it takes for the entirety of the room population to evacuate the room. This does however not take into account the fact that emergency situations are unpredictable and that the critical time that the room occupants have to evacuate can sometimes be tragically short. In a fire, sometimes the time can be as short as one or two minutes[1], and for a portion of this time, the fire is smaller and undetectable, growing and spreading. In these cases, any amount of planning might still fall short when it comes to evacuating everyone safely. What these results show, however, is that there could possibly be other ways of designing rooms and evacuation plans that lead to more lives saved; even if a certain layout doesn't yield the fastest total evacuation time. There could be great value in looking at the partial evacuation times of layouts that yield comparatively similar total evacuation times. Looking at figure 5.3 again, table layout B, yielded only a marginally slower total evacuation time than table layout D, while yielding a faster evacuation time for as many as 80% of the room population.

Looking at partial evacuation times however when designing spaces does pose some serious ethical implications, which will be discussed in the next section.

5.2 Ethical implications

Attempting to standardize anything where the user demographics are as wide as they come, will always present a struggle; and evacuation planning is no different. People come in all shapes, sizes, and capabilities, which means that something that might work terrifically well for some, might be a problem for others.

When it comes to designing interior layouts based on paths for instance, as discussed in RQ1, the paths will have to vary in width. Having more table groups yields more possible paths towards the exit, but it also means that the paths themselves become narrower due to the added objects in the room. This could potentially pose serious problems for larger people, or people with mobility disabilities who use wheelchairs or other assistance devices. This can often generally be handled by widening the net, so to speak, to include everyone by taking the greatest common denominator; which in the case of accessibility would be opting for wider paths. But when it comes to things that relate to people's immediate safety, neglecting approaches that might lead to more lives saved becomes more difficult.

This becomes more evident when looking at partial evacuation times, which is discussed in RQ2. Using a metric that indicates that some people might have their safety neglected for the sake of ensuring others' is highly troublesome - even if it does mean that more lives would be saved overall.

[1]https://www.nfpa.org/Public-Education/Staying-safe/Preparedness/Escape-planning

There are ways, however, of integrating partial evacuation times into evacuation planning and reaping the benefits without having to make that sacrifice. One way would be to only look at layouts that yield roughly similar total evacuation times but that differ in their partial evacuation times.

Regardless of the outcome, we should always be careful about implementing methods that chip away at our ethics, but at the same time we should not neglect researching and studying them - because they could prove to be a vital step in advancing safety regulations.

5.3 Risks and limitations

Attempting to simulate human behavior and drawing conclusions from the results always comes with a caveat. It is exceedingly difficult, if not impossible, to accurately simulate human behavior in its entirety. The intuitive human senses and panic behaviors are very complex and unpredictable, and they can be challenging to implement accurately into a crowd simulation. Some individuals might try to climb over others, or try to jump over, or crawl under, tables. Some might freeze up and not even attempt to flee, while others might be mislead by their senses and choose ineffective routes. This leads to simulations, like the one used in this study, missing some key components that uniquely composes us as humans.

Another limiting factor is the immobility of the furniture in this study. This could be something that changes the simulations drastically, while some evacuees might escape quicker, others could also have their chosen paths blocked by the moved tables. This is something that could potentially be implemented, but it would still be difficult to simulate accurately. The crowd would not necessarily always be pushing any tables away in front of them, only a select few might choose that option, which poses a challenge in the implementation.

The tests did not include collision handling which could also be a limiting factor. The simulation was not as prone to bottlenecks created in narrow paths which could potentially make the process take longer. However the intention with this study was to evaluate the paths created by the table layout and the used algorithm ensured that agents could not pass through each other. This meant that the tests still yielded evacuation processes that were faithful to the table layouts, only minor clipping of the table edges occasionally occurred.

5.4 Future work

While the results did not lend themselves to any strict conclusions regarding the connection between number of paths and evacuation time, there were interesting behaviors noted in the consistency in the evacuation processes between layouts. More table groups, and by proxy more possible paths, seemed to strongly correlate with more consistent evacuation times. Further research into this could yield valuable information. This could potentially mean that in real world scenarios with real human behavior, layouts with less paths are more prone to obstructions, or other issues that lead to greater deviations in the process. A crowd simulator that includes some level of panic and individuality could highlight this. It would also be valuable to include a variety of locomotion methods between the agents to test the accessibility aspect of it.

Research into how we as humans choose paths could yield valuable information when it comes to designing the interior of classrooms. It is not necessarily the case that, in an evacuation process, evacuees always choose the shortest path. Intuitively we might choose less congested paths, or paths that seem more straight forward, or even get overwhelmed by the amount of paths and freeze. More insight into this could help to develop more accurate simulators that allow for better evaluations of how the number of paths affect evacuation times.

Further research into partial evacuation could also prove to be interesting. Simulating actual emergency situations with consequences in KTH classrooms, such as rapidly spreading fires, could highlight the value in faster partial evacuation times. Emergency scenarios can vary, even between the same type of emergencies. In some, the critical time for safe evacuation might be far too short for a full evacuation. In these cases faster partial evacuation times could save more lives.

6 Conclusion

The results showed that the table layout in a classroom did impact the evacuation time of the classroom. The standard table layout used in classroom E31 at KTH Royal Institute of Technology, layout A, with nine table groups, yielded the fastest evacuation time. While the layout with three table groups, layout C, yielded the slowest. The results did not strictly show any correlation between the number of table groups, and by proxy the number of paths available to the evacuees, and the evacuation time of the room. They did, however, show a strong indication that certain behaviors that arise between layouts, lead to more consistent evacuation times. More specifically the results showed that having more possible paths towards the exit lead to more consistent evacuation times, while having less possible paths lead to less consistent times.

The results also showed that the evacuation time of a room did not increase at the same rate for percentages of the room population between the different table layouts. While some layouts yielded faster total evacuation times, i.e. the time it takes for the entirety of the room's population to evacuate, they also yielded slower partial evacuation times, meaning the time it takes for percentages of the room's population to evacuate. The layout yielding the fastest evacuation time, layout A, had a slower partial evacuation time for 60% of the room than layout D, which yielded a slower total evacuation time. This idea was even more evident in layout C, which had the slowest total evacuation time, but the fastest partial evacuation time for 20% of the room.

References

[1] Willy Liu and Daniel Parhizgar. "Evaluating Classroom Evacuation with Crowd Simulation". KTH, 2018.

[2] Dirk Helbing. "A mathematical model for the behavior of pedestrians". In: *Systems Research and Behavioral Science* 36.4 (1991), pp. 298–310.

[3] Dirk Helbing, Illés Farkas, and Tamás Vicsek. "Simulating dynamical features of escape panic". In: *Nature* (2000). DOI: 10.1038/35035023.

[4] Shi Dongmei, Zhang Wenyao, and Wang Binghong. "Dynamics of Panic Pedestrians in Evacuation". In: (2017). DOI: 10.48550/arXiv.1701.01236.

[5] Yale. *Classroom Seating Arrangements.* https://poorvucenter.yale.edu/ClassroomSeatingArrangements. (Visited on 03/31/2022).

[6] Jack Shabo. "High Density Simulation of Crowds with Groups in RealTime". KTH, 2017.

[7] Rahul Narain et al. "Aggregate Dynamics for Dense Crowd Simulation". In: *ACM trans. Graph* 28.5 (2009). ISSN: 122:1–122:8. DOI: 10.1145/1618452.1618468.

[8] Craig Reynolds. "Flocks, herds and schools: A distributed behavioral model". In: *Flocks, herds, and schools: A distributed behavior model. Proceedings of ACM SIGGRAPH 87* July 1987 (1987), pp. 25–34. DOI: 10.1145/37401.37406.

[9] Suiping Zhou et al. "Crowd Modeling and Simulation Technologies". In: *ACM Transactions on Modeling and Computer Simulation (TOMACS)* 20.4 (1987), p. 20.

[10] Xiaoping Zheng, T. Zhong, and Liu Mengting. "Modeling crowd evacuation of a building based on seven methodological approaches". In: *Building and Environment* 44.3 (2009), pp. 437–445. DOI: 10.1016/J.BUILDENV.2008.04.002.

[11] Adrien Treuille et al. "Continuum crowds". In: *ACM Trans. Graph. - Proceedings of ACM SIGGRAPH* 25.3 (2006), pp. 1160–1168.

[12] Nicolas Bain and Denis Bartolo. "Dynamic response and hydrodynamics of polarized crowds". In: *SCIENCE* 363.6422 (2019), pp. 46–49. DOI: 10.1126/science.aat9891.

[13] Johan Berglund et al. "High-density Real-time Virtual Crowds via Unilaterally Incompressible Fluid Simulation". KTH, 2015.

[14] Gary A. Cziko. “Unpredictability and Indeterminism in Human Behavior”. In: *Educational Researcher* 18.3 (1987), pp. 17–25.

TRITA-EECS-EX-2022:458