A

Thesis Report

On

Pedestrian Movement Analysis in New Lecture Hall Complex IIT Roorkee

Submitted by

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this thesis report entitled **"Pedestrian Movement Analysis in New Lecture Hall Complex IIT Roorkee"** submitted by **Rajkumar Chotia** bearing the Enrollment No. 19524013, in the partial fulfillment of the requirements for the award of degree of Master of Technology in Civil Engineering with specialization in Transportation Engineering, submitted to the Department of Civil Engineering, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out under the supervision of **Dr. Amit Agarwal** Department of Civil Engineering IIT Roorkee. The matter embodied in this report has not been submitted for the award of any other degree.

Date: 25th Jane, 2021 RAJKUMAR CHOTIA

Place: Sridungargarh Enrolment No: 19524013

I certified that the above statement made by the students is correct to the best of my knowledge and belief.

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ABSTRACT

Pedestrian movement analysis plays an important role in designing of many facilities of wide range from commercial hub or a normal residential building to some transportation infrastructure. The focus of this study is to study the behavior of pedestrian inside a building during emergency situation by analyzing the various aspects such as velocity, flow, density etc. Ultimate goal here is to find out the best possible route for everyone to exit the building through emergency door and main entry gate during emergency situations with the help of various simulations and their comparison. For the simulation generation there are many tools but here in this study they are generated with Jupedsim which is open source software. Analysis and comparison of these simulations is done with the help of Jupyterlab. The study shows that the velocity of pedestrians is almost constant at the main exit doors while it shows the decreasing trend at the door of lecture hall whereas the density at the lecture hall door is much higher as compared to the density at main exit. The geometry makes a significant impact on the evacuation time as the congestions were observed around the corners near to the exit doors. The evacuation time is proportional to the number of pedestrians inside the facility and it keeps on increasing if number of pedestrian increases. Evacuation time also depends on the distribution of pedestrians inside the building and it can vary according to the presence of pedestrians near or away from the main exit

Keywords: pedestrian behavior, evacuation, exit strategy, pedestrian flow characteristics.

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CHAPTER 1: INTRODUCTION

1.1 General

In the constantly developing world, facilities are continuously increasing. One of the challenges in front of the planners is to develop these facilities in such a way that maximum people can be accommodated in minimum space. This tendency of accommodating more people in less space is the driving factor for interest in studies of pedestrian movement. With this many of people in these facilities, there is the need for proper planning for evacuation in an emergency situations for the safe evacuation of all people, to achieve this goal we need to study the movement of pedestrians in a facility. A pedestrian is basically a person using any facility without a vehicle or say on his/her feet; it includes the person with disabilities also. Wherever there is this pedestrian environment interaction occurs, the safety issue of pedestrians rises and to keep people safe at any cost we need to understand their behavior and requirement. This concern over the safety of pedestrians is there for indoor as well as outdoor pedestrians. As we all know during the emergency situation, there are very strict warnings against using the elevator and to evacuate the facility it is advised to use the emergency exit strategy developed for such kind of situations because there are good chances of having trouble with the electric supply line of the elevators during the incident and that can cause the people to get stranded in elevators. When we talk about the evacuation of the taller buildings then it has a totally different aspect to it which depends on kinds of the pedestrians using the facility, their age group their gender, etc. for example if we need to evacuate a tall building and many people are using the facility are aged and use of the stairs for them is not feasible. So in this kind of scenario we need to think in different ways to make the evacuation procedure smooth for everyone. Designing an indoor pedestrian facility is a complex task as planner needs to take care of the safety of pedestrian as well as the economy of the project. Here three factors are most important; pedestrian behavior, physical environment around them and modeling. *Kalakou and Moura (2014)* found that the integration of these three is far more important than the individual research of each aspect but the ultimate results were such that even if we talk about any two factors combine, not sufficient research has been done.

Apart from the physical structure of the building, the use or let’s say the purpose of the facility also plays an important role in deciding the exit strategy. The facility may be of a residential type, it may be the commercial facilities such as offices and malls, it may be the industrial buildings, it may be hospitals, etc. Based on the type of facility, the number of occupants can vary during the day. For example, during night time there will be a very low number of occupants in malls but have the maximum number of people in residential buildings. Similarly, for hospitals we can say that occupants remain almost same throughout the 24 hour period. Also, we know the kinds of occupants in different kinds of the facilities are not same. So we need to take all these factors into consideration while deciding the exit strategy for the particular type of facility. For accounting for the above mentioned factors we need to understand the effect of the geometry of the facility which includes the size of rooms, corridors, exit gates, location of emergency exits, etc. and the pedestrian characteristics which includes the distribution in the geometry, age and gender distribution, their moving speed, etc. To understand these factors we need to run the various simulations with different distributions inside the geometry and also with respect to the age and gender.

The occupants of the building also play an important role in deciding the evacuation planning of the facility. The most common examples in such scenarios are the hospital buildings where patients cannot evacuate themselves, old age homes where most people are of age above 60 years, nursery or primary schools where children of below 6 year age are there. In all these situations the evacuation process is very tedious as most of the occupants need help in leaving the facility in time of emergency. So from this prospective, we need to be extra careful while deciding the evacuation plan of such buildings. The preparation of an evacuation plan is one thing and finding the efficiency of that plan is another thing. For having a better plan, planners need to run the simulations for different emergency situations with a different kind of plan layout. In these kinds of exercises, a large number of variables should be included in the simulation in order to have a good emergency evacuation plan which works in a wide range of emergency situations. When the simulations are run for these situations, we learn a lot of things related to pedestrian behavior in emergency situations. The factors which affect the pedestrian behavior includes the distribution of pedestrian by age, distribution by gender, it also depends on the presence of specially-abled persons in the crowd. Also the geometry of the facility such as corridor, stairs, bottleneck etc. plays an important role in deciding the path of pedestrians.

To understand the simulation of pedestrian movement we need to understand their behavior while using or evacuating any facility. This includes the study of the basic fundamental diagrams of the pedestrian flow to understand the variation of speed, density and flow with respect to each other. Also the effect of various factors including a wide range from facility characteristics and pedestrian distribution across gender and age to type of emergency is also needed to analyze to better understand the simulation and then for better evacuation plan design. The behavior of pedestrians can differ inside and outside of the facility so there is the need to remain extra careful while deciding the final evacuation plan of the facility. To summarize the entire process of determining the path pedestrians to move out from facility**,** *Farr et al. (2012)* shows that this is a simple process of finding a way to destination with the help of cues from surrounding environment and it depends on interaction of human behavior and surrounding environment. The suitable model for this particular exercise is that where we include the cognitive and psychological behavior of the people along with physical characteristics of the surroundings.

1.2 Need of the study

In modern world which is constantly developing and has the scarcity of space, most of people are residing or working in congested space or at a place which has a lot of other people are working or residing along with them. In such scenarios there is a lot of troubles in vacating the facilities when there is the need in emergency situation such as fire, earthquake etc. Many people lose their lives in these situations due to lack of proper evacuation planning and necessary infrastructure which provides the assistance while evacuating the facility. In such situations people react in unpredictable manner because of uncertainty of situation and also because of poor decision making capability in emergency situations due to which they generally do not follow the safety guidelines and cause the chaotic situation.

Emergency evacuation is basically the immediate escape of people away from the facility in order to minimize the loss of life. To perform the above mentioned task perfectly we need to have a proper planning. These evacuation plans are developed with the help of strict regulations, standard practices and running various simulations to ensure that every occupant's need is fulfilled with the help of many signs and alarms. So to properly evacuate the facility we need to have full proof evacuation planning. It ensures that all the required measures are implemented in order to safely evacuate the occupants. Evacuation plans for facilities are mandatory in most of the countries and it helps in providing a proper chain of command. It also helps in calming the nerve of panicked occupants. If the residents already know about the emergency evacuation planning of the facility, there will be no chaos and people will follow the instructions more carefully and calmly. The evacuation planning is not that simple and depends on many factors including building characteristics, type of emergency to the occupants' distribution across gender and age. User behavior plays an important role in deciding or planning the various aspects of the evacuation plan and to study the user behavior we need to simulate the various scenarios with various distributions of pedestrians in the facility to understand the effect of gender, age etc. on the evacuation plan.

The seismic vulnerability of India is very high and as per the data of *SEEDS India 2019*, 110 districts across the country fall in the zone V, the highest earthquake zone. Since most of the buildings in rural areas are not as per specification leads to the major loss of life as this is the common saying that "earthquake don't kill people, buildings do". Another factor here we can consider is the various fire related accidents that happen and causes the death of residents in absence of proper evacuation plan. As per news report form *dw.com* there are nearly fourteen thousand buildings in metropolitan city like Mumbai alone which are more than 50 year old and at risk of accident due to lack of maintenance. As per NCRB data there are around 35 deaths per day due to fire accidents in India and it's a huge loss to humanity. If we go into more statistics, as per the analysis of 195 nations published by *Global Disease Burden (2019)*, India has recorded 1.6 millions of fire accidents and 27027 deaths out of 9 million fire accidents and 1.2 lakhs deaths globally. Now when we talk about the general fire related accidents in India which is related to fire in residential and commercial buildings, it is also noteworthy as per *ADSI Report (2018)*, the number of fire accidents and the death caused by these accidents has increased significantly.

Another aspect of the accidents is the aftermath of it and if there are a lot of people inside any facility, they will panic and that can cause a stampede. The main reason behind this type of aftermath result is the absence of proper planning. Stampede is also a measure cause of concern and this can be avoided by providing the needful information at right time so that occupants follow a set of instructions rather than just running blindly. If we look at the statistics, as per news report from Times of India, around 3000 people have been died in these kinds of accidents in past 15 years or so. There are some major incidents in country for example 2005 Mandher Devi temple stampede in Maharashtra, 2008 Chamuda Devi temple stampede in Rajasthan, 2011 Sabrimala stampede in Kerala, 2013 Ratangarh Mata temple stampede Madha Pradesh where more than 100 people lost their lives in every incident.

This leads to the need of providing proper exit path to the pedestrians this need to take various aspects into consideration. To study these aspects we need to analyze the movement of pedestrian along with the building features as well as the type of emergency. On the basis of these aspects we try to study the pattern and define a best suited exit strategy to a given facility. For understanding the different aspects of the pedestrian movement, flow diagrams are an important tool as per *Rao et al. (2017)*. Pedestrian flow theories are also helpful to the planners for management of big crowds but with enhancement of technology, we can always find something new to better serve the purpose. There are also some state of the art methods to understand the movement and these are mostly computational methods.

1.3 Objectives of the study

The present study includes the pedestrian movement analysis in new lecture hall complex of IIT Roorkee which sees the student footfall throughout the day. This building has three exits out of them two are emergency exit and one is the main entrance and exit gate. Lecture hall complex is multistory building but in this study the main focus is on the ground floor so that with the some findings and trends from it can be used to develop the model. Ground floor consists of five lecture halls, seven corridors to access the halls and the stairs and elevator complex. The primary objectives of the study are

- Study the various attributes of pedestrian movement such as velocity, density, flow etc.
- Study of the factors affecting the movement of the pedestrians
- Analysis of evacuation time

1.4 Organization of report

The progress report on the topic “Pedestrian Movement Analysis in New Lecture Hall Complex” consists of five chapters which are:

- Chapter 1: This chapter gives the basic introduction of the topic and defines the objectives of the study.
- Chapter 2: It consist the review of different studies done in past.
- Chapter 3: It explains the methodology with which work has been done.
- Chapter 4: This chapter includes the analysis and results
- Chapter 5: It consists of conclusions and future works needed to be done.

CHAPTER 2: LITERATURE REVIEW

2.1 Pedestrian Behavior

The study of pedestrian movement has a very vast scope from designing of various transportation facilities to the design of vehicles but most importantly it is very helpful in the safety of pedestrians while using these facilities. Since the behavior of human is very unpredictable, we need to analyze very large pool of data and experiments to give generalized information regarding a particular fact or habit. Since our main focus is to study the pedestrian movement inside a building, we stick to that and tried to find out some factors that affects the decision making of pedestrian inside a building or a facility. Planning an indoor pedestrian facility is of utmost importance in modern times because of continuously developing world. *Kalakou and Moura (2014)* found that there is three basic things we need to keep in mind. First one is pedestrian behavior which is the characteristic of pedestrian itself; second one is the physical environment around them and last one is the modeling. While designing the facility the integration of these three is important and literature review suggests that sufficient research has not been done. For improvement is has been suggested to use the cognitive science in the models to give the better results. A lot of work has been published which shows the effect of physical features of the environment on the pedestrian movement but there is limited work has been done which use the syntactic measures to understand the pedestrian movement. *Kamruzzaman and Sharmin (2017)* did the review of such studies in order to get the answer of some frequently asked questions including measures used to explain pedestrian movement, magnitude and direction association of space syntax with pedestrian movement, which measure has more consistent relation with pedestrian movement etc. Here they tried with four different syntactic measures including integration, connectivity, choice and control.

Integration: defines the closeness of given street to all other street and it calculate the distance in terms of turns and directional changes.

Choice: extent to which given streets is the shortest path between other streets.

Connectivity: number of streets that are directly connected with given street.

Control: measures the degree to which a space controls access to its immediate neighbors taking into account the number of alternative connections that each of these neighbors has.

They found that most of the syntactic measures will promote the pedestrian movement and has positive effect. If the proper information is provide to the pedestrians then the integration and choice plays most important role in finding the path as pedestrians prefer the visual shortest path in most of the cases. The pedestrian behavior plays an important role in designing the pedestrian facilities such as cross walks ad many indoor facilities. Macroscopic features of pedestrian flow which is generally depends on the behavior of the pedestrians is important. *Daamen and Hoogendoorn (2007)* took upon the free speed distribution of the pedestrians. Free speed is basically the speed with which pedestrians walk in he or she is not surrounded by other pedestrians and his or her movement is not hindered by surrounding features. Thus it depends on the physical infrastructure as well as on the pedestrian features such as age, gender etc. But the measurement of the free speed of pedestrians is not that easy since we need to choose only those pedestrians who are walking at free speed from the pool of pedestrians. Since speed of the pedestrians can differ so we need to define some constraints in order to get the proper idea of it. One of the interesting finding of this paper is that pedestrians who has high walking speed will face more constraints than the pedestrian who has low speed.

2.2 Modeling and Simulation

Pedestrian movement should be analyzed and modeled properly in order to have comfortable movement in normal situation and safe evacuation in emergency situation. To model the pedestrian movement inside a building, various studies has been done and *Chraibi et al. (2019)* designed a collision free velocity model to analyze the movement as during any emergency situation it is inevitable that due to spontaneous reaction of pedestrians they do not move in systematic manner. With the help of such models we can look into the factors which are causing collision situations and how we can design the facility such that even during spontaneous reaction of pedestrians they have minimum collisions. Mostly when we talk about the pedestrian behavior analysis we try to simulate the behavior with the help of different models. These models also can vary significantly as our problem can be varied from evacuation of a small building having few people to an entire city. *Lämmel et al. (2016)* shows that depending upon the precision and complexity required we can choose different models ranging from velocity based or force based linear model to the queue based model which has limited physical interaction. When we want higher precision then computation will be very complex thus for making computation a bit simpler we are going to have a compromise with precision. But for maintaining the precision as well as simple computation we can go for hybrid models which give better results under such circumstances.

Liao et al. (2014) has done an experiment where they tried to analyze the movement of pedestrians in bottleneck and found that density and velocity does not depend on the width of bottleneck and the flow has a linear relation with the width of bottleneck. There are some other factors also such as length of bottleneck but effect of those is visible only when steady state data was used for experiment. Thus so find out the impact of some other factors such as the characteristics of holding area, purpose of pedestrian, distance of bottleneck from holding area, composition of pedestrians etc. we should use the steady state data. Since we are always concerned with the safety of pedestrians especially in buildings, we also do some innovative research to achieve our goal. Our goal is to always remain ahead of the incident and predict that well before or in time sufficient to evacuate all the people from facility. *Wagoum et al. (2012)* talks about such a system which tries to give the most appropriate evacuation plan with the help of data provided to assistance system for next few minutes which get changed regularly according to changing scenarios in the building. This is lot more helpful as it gives the heads-up to management to remain better prepared for any emergency situation.

For better planning and design of buildings for safety of people it is needed to understand the pedestrian dynamics better. Similar study is done by *Chraibi et al. (2012)* and found that for better results of such assistance system, different pedestrian models should be integrated and they also suggested of using different runtime optimization to include more factors that affect the pedestrian interaction with each other and also with the physical environment around them. For further understanding, there is a scope of analyzing the data obtained from automated pedestrian counters. *Zhang and Seyfried (2013)* done some experiment to better understand the dynamics and found that unidirectional flow is higher than the bidirectional flow. They also perform the experiment on different geometries. For example they found that flow in short bottleneck has higher than long bottleneck and also found that straight corridor has highest flow. Thus it is evident that while performing the experiment we should always change the parameters for better results for different geometry. *Wagoum et al. (2012)* has tried to do the event based modeling of pedestrian behavior when ultimate goal of each of them is to leave the facility. They used the different modeled strategy which includes shortest path and quickest path. Analysis of the effect of these models has been done on evacuation time, time spent in jam, size of jam etc. and found that the shortest path strategy does not affected by initial distribution of pedestrians. It also shows that faster evacuation reduce the jam time and jam size.

For analysis of interaction of pedestrians while moving or evacuating, there are different models and one of them is force based model which describes the physical and social interaction of pedestrians. *Chraibi et al. (2011)* has describes this model and tried to explain some of the factors including velocities of pedestrians as well as the violation of Newton's laws and provided a generalized force based model. They also suggested that direction choice of pedestrian plays an important role in modeling and it needed to be further investigated. On the basis of these findings they defined a generalized centrifugal force model which represent pedestrian as 2D elliptical figure. *Schadschneider et al. (2010)* has done the comparison of regular circular shape of pedestrian with elliptical shape and it shows that elliptical shape of pedestrian is having good agreement with experimental data. The main aim of this is to provide a quantitative description of pedestrian movement in different geometries along with fundamental diagram of flow. Since fundamental diagrams of flow are very helpful in understanding the movement of pedestrians, *Zhang et al. (2011)* performed an experiment with four different methods of measuring the different attributes of flow diagrams and found that results obtained from various method agreed well and concluded that flow diagrams for same facilities are comparable but if we talk about different geometry then they differ significantly.

When the talk is about the movement analysis of pedestrian in a facility then the microscopic model is the first thing that comes to mind as this type of models includes the interaction of pedestrians with the surrounding. *Nick Tyler and Elvezia M. Cepolina (2003)* describe the interaction between pedestrian and the surrounding environment. They found that such type of models is better for evaluation of accessibility especially when there are elderly or disabled people. Pedestrian movement is very complex and it can be analyzed with two approaches named as microscopic approach where the focus is the every single pedestrian and their movement, on the other hand macroscopic approach focus on the bigger picture and assume pedestrians as object where they cannot decisions. Simulation results from both approaches are quite different so *Yeo et al. (2016)* designed a model which used the merits of both approaches. They modify the original model to make the calculation fast and also added the thinking component so the pedestrian can make decision. This makes this model special as agents in this can decide on their destination on the basis of situation around them. *Kyug Hoon Lee et al.*

(2018) has done a study on visual factor related pedestrian simulation model and this helps is in understanding the spatial use by pedestrians based on visual inputs. This model verified the hypothesis that relation between human and physical substance within the visibility can generate different movements. *W. Zhu et al. (2016)* took a step ahead by using the psychological and behavioral characteristics in analyzing the emergency evacuation. They proposed a behavioral emergency evacuation model after comprehensive psychological evaluation along with behavioral analysis. This proposed model gave the good results while evacuation and is helpful in improving emergency evacuation. *Hussein and Sayed (2015)* developed a bidirectional agent based simulation model which counts for heterogeneity and intelligence of pedestrians. The primary focus of model was to predict the accurate trajectory of pedestrian. The calibration of model was targeted for minimizing the error between true trajectory and predicted trajectory and it was evident that their accuracy was about 95 percent. *Jalalian et al. (2011)* proposed a new method for simulating the pedestrian behavior in urban environment. The analysis mainly depends on speed, trajectory ad angle between moving direction and gazing direction. It basically validate that a special looking feature of the facility can affect the movement of pedestrian. *Nuo et al. (2012)* has done the simulation for optimal exit strategy with dynamic model and studied various aspects including evacuation time and density of pedestrians with the width of the exit. They found a linear relation with evacuation time and width of exit whereas negative exponential relation in density and width. The optimal exit layout system was given by keeping the factors such as exit widths, injuries due to collision, safety guiding etc.

While modeling the operational behavior of pedestrians, primarily we face the issues of pedestrian representation and speed choice. To overcome above mentioned issues *Noland and Ishaque (2008)* focused on pedestrian speed, their compliance to signals, their gap acceptance and their speed-flow-density relationship. Operational modeling is a complex engineering and behavioral issues and mostly we are interested in behavioral issues such as how they interact with each other, speed of movement etc. when we talk about the engineering side, mainly is the focus on traffic control devices. The factor which makes the pedestrian simulations difficult is that unlike vehicular traffic which have fixed path and direction to move, pedestrians has multidirectional spatial paths. Another thing is the route choice and origin & destination as both of these are not as specific for pedestrians as for vehicular traffic. Thus to improve the modeling of pedestrians significantly we need to understand these behavioral characteristics well.

Pedestrians speed is also a very critical factor and it has been seen that if we reduce the speed of the pedestrians even by small margins, it is observed that there is significant increment in the travel time. At microscopic level the movement of pedestrians depends on presence of other pedestrians, whether they are moving as a group, individual characteristics, situation and purpose or type of trip and the physical infrastructure around them.

2.3 Pedestrian Flow Studies

Majority of the pedestrian flow studies are done to design the pedestrian facilities. *Gupta and Pundir (2015)* showed that majority of the studies have the linear relationship in speed and density. Very few of them have the logarithmic or exponential relation. Nowadays studies are including the factors such as age, gender, and physical strength and making it handier in modern facility design. Also there is this major factor which may affect the results is the place of the study as in case of developing nations the crowds are much higher and facility provided is not up to the standards in terms of space means less area will be there for movement which will affect the final results ultimately. Apart from this they identify the areas where more work can be done includes the effect of gradient and the presence of physically disabled persons in the mix on the flow characteristics.

While modeling the operational behavior of pedestrians, primarily we face the issues of pedestrian representation and speed choice. To overcome above mentioned issues *Noland and Ishaque (2008)* focused on pedestrian speed, their compliance to signals, their gap acceptance and their speed-flow-density relationship. Operational modeling is a complex engineering and behavioral issues and mostly we are interested in behavioral issues such as how they interact with each other, speed of movement etc. when we talk about the engineering side, mainly is the focus on traffic control devices. The factor which makes the pedestrian simulations difficult is that unlike vehicular traffic which have fixed path and direction to move, pedestrians has multidirectional spatial paths. Another thing is the route choice and origin & destination as both of these are not as specific for pedestrians as for vehicular traffic. Thus to improve the modeling of pedestrians significantly we need to understand these behavioral characteristics well. Pedestrians speed is also a very critical factor and it has been seen that if we reduce the speed of the pedestrians even by small margins, it is observed that there is significant increment in the travel time. At microscopic level the movement of pedestrians depends on presence of other pedestrians, whether they are moving as a group, individual characteristics, situation and purpose

or type of trip and the physical infrastructure around them. When we talk about the particular cases to study the pedestrian flow then bottleneck section is most common. *Daamen and Hoogendoorn (2007)* did a research on the flow relationship of pedestrians passing through the bottleneck section. They found that pedestrians passing through the same cross section may have different flow characteristics.

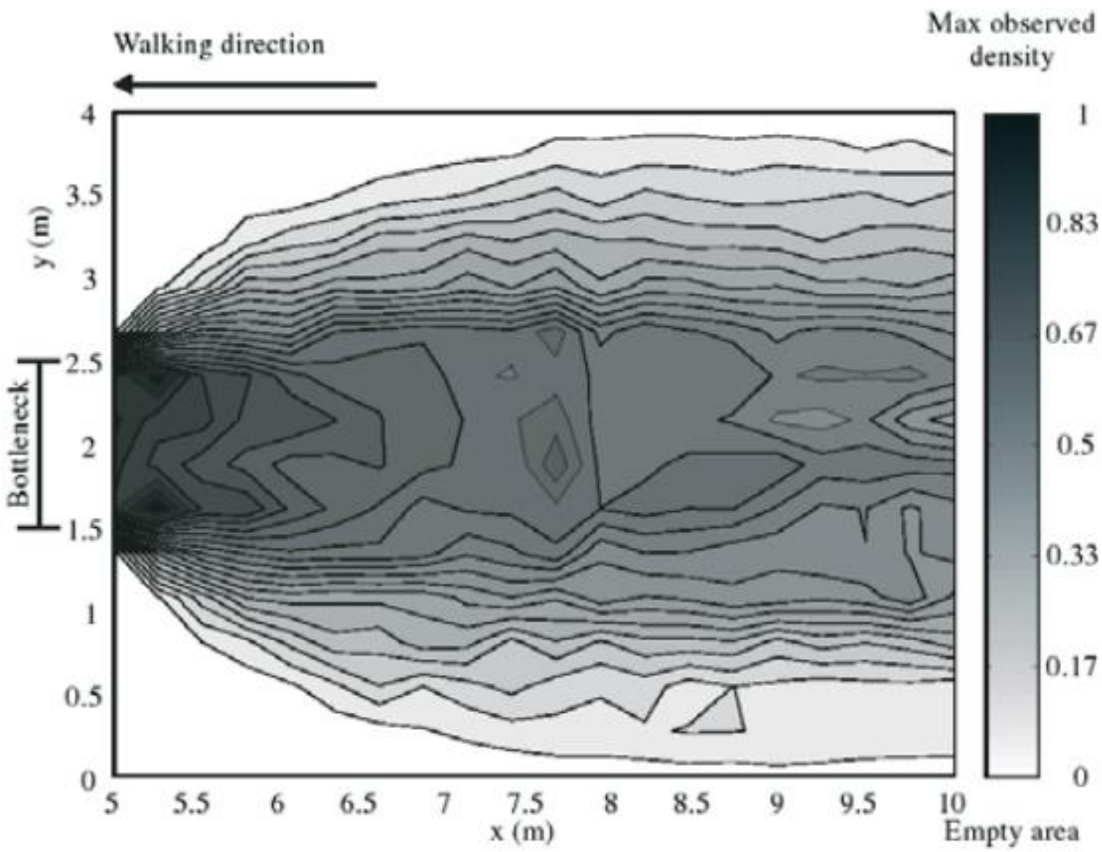

Figure 2.1: Average density at the upstream of the bottleneck *[Daamen and Hoogendoorn (2007)]*

The observations show that pedestrians will form a funnel shape on the upstream of the bottleneck and it is evident from the above Figure1 that the density is not uniform. The interesting finding of this is that apart from the total area if we talk about the density across the sections at any particular location, it is also variable. We can see that inside or middle portions the density is higher and speed is low means congestion is there but in the side portions pedestrians will move freely with higher speeds. So if we are trying to get the congestion branch of fundamental flow diagram, we need to identify the homogeneous locations rather than the whole section. Pedestrian movement is a complex phenomenon as compared to the vehicular traffic as they have 2 dimensional movement opportunities. Secondly, the movement path for the vehicles is well defined whereas this is not the case with pedestrians and also the cultural difference in the pedestrians makes the case more difficult to analyze. Fundamental diagram of pedestrian flow shows the relation between macroscopic characteristics including speed, flow and density. The shape of the pedestrian flow diagram is not unique and it depends on the pedestrian characteristics such as age, gender etc. and the physical environment of the facility. These diagrams help in determining the value of LOS, capacity of the facility and developing the dynamic simulation models. Thus it is evident that to design an efficient transport facility, understanding of the fundamental diagrams is necessary. *Rao et al. (2017)* did the review of various pedestrian flow diagrams and found that there is the need to differentiate the experimental, field and simulation fundamental diagrams by providing suitable adjustment factors. Secondly, there is the need to have a further analysis of flow density relationship of various geometrical shapes as the exact extent to which the fundamental diagrams gets affected by the physical characteristics is not known. Some of the striking points from the study are that most of the researchers interested in developing the flow relations in controlled experiments but they are not accurate because in such situation it is possible that pedestrian may not behave same as in a real emergency situation so there is the need of doing some field studied. The walking speed of the pedestrians depends on the facility purpose of the trip thus it is not advisable to use the result from one study to design a different type of facility and also the measurement methods have a significant effect on the results so it should be studied further in order to make some adjustments. One more interesting study has been done by *Bukacek et al. (2017)* to find the reasons for high variance in travel time. This was explained by the heterogeneity of the crowd as some of the pedestrians were able to effectively push the crowd but others got stuck. Also some of them chose the walk around paths instead of going through the crowd and thus they relate the travel time with the size of crowd in front of the bottleneck section. This ability of the pedestrians to push the others is partially related with the aggressiveness and willingness to move ahead of the other pedestrians. The pedestrians who chose the walk around path are not aggressive and they use the situations to their benefit by reacting in a better way.

CHAPTER 3: METHODOLOGY

This chapter basically includes the methodology with which we have done our analysis of pedestrian movement in new Lecture Hall Complex. The important parts of this are study area, data required, software used etc. The basic idea is to get the insight into pedestrian movement using simulation with the help of any software which gives us the data related to pedestrian movement such as velocity, density, time to leave the facility and then plot some curves to compare the results. First part of the process was to choose the area or location where we can do the study and then to determine what we need to collect to get the desired results. Both the above mentioned processes are simultaneous to have a better combination of the area and data. Here comes the next step of analyzing the collected information in order to fulfill our requirement of getting the results. To analyze the current data as well as to generate some more data to make some conclusions there was the need of using software which can run the various scenarios in order to get the better insight.

3.1 Study area

The idea of analyzing the pedestrian movement gives the freedom of choosing the study are of two types. Frist one is the area which is mostly outdoor such as pedestrian walk ways, signalized intersections, any market street where they are not inside the any building. Second one is the area which is inside of the building such as airport terminals, railway and bus stands, shopping malls etc. The idea behind choosing an indoor area to study the effect of some building features on the pedestrian movement and finding whether it is different from the pedestrian movement outside the building. Also this kind of study is really helpful in checking the emergency exit plan of the building and if it is not ready then in preparing it.

The study area includes basically the New Lecture Hall Complex of IIT Roorkee. This is a multistory building with 5 classrooms (two has capacity of 256 each, another two has capacity of 155 each and one has the capacity of 144 students) at every floor and has near about capacity of each floor is 966. This means at a time we can accommodate 966 students at a floor and this will give the wide variety of data as we can change the number as per our requirement at every floor and in different classrooms as well. After hostels in campus this is the only building where we get maximum number of pedestrian footfall. One more advantage here is that we can get the data on the basis of gender also, it is not the part of our analysis but it can be done if required. The primary reason behind using this site is that we can get the wide variety of scenarios by varying the number of agents and all these scenarios gets created at this building in real situations during a regular working day. Since this is a multistory building it will give the simulation results at stairs also we can analyze that how will the pedestrians from different floors react to any emergency situation.

3.2 Data required

The data requirement is basically depends on the objectives of the study and the process of achieving those objectives. Here clearly we are interested in the velocity, density and the flow of the pedestrians so their number and distribution is pretty important. Secondly we are working inside the building thus it is necessary to have all the building characteristics. Since in the process we are using the Jupedsim software which has different components and need different set of data for proper functioning. The process includes the use of geometry of the building in which we are trying to study the pedestrian movement, then number of pedestrians inside the building. Then the velocity and density of various scenarios in order to plot and compare the different results and finally in between these steps there is intermediate data requirement inside software.

First of all for generating the geometry with the help of JPSeditor, floor plans of entire building are required. The floor plans will give the size of various classrooms and corridors. The size of main entry and exit is also important along with the size of entry and exit of various classrooms and apart from that it will give the information regarding the stairs and elevator complex which will be useful when we connect the different floor levels with each other in geometry. In emergency situations mostly there is the possibility of emergency exit, we get the information regarding emergency exit also by floor plan. Along with floor plans, the maximum capacity of the lecture hall is required for varying the number of agents in simulations as per real situations. In this study we will not be using the full capacity of lecture halls to relate it with real situation as generally there are 60-70 students sitting in a classroom but in later stages we can do the analysis for full capacity also. Now with this data we will generate the geometry and then with the xml format of geometry file which includes the dimensions of the lecture halls and corridors, we will visualize the geometry of the ground floor of lecture hall complex.

This geometry file will be useful in defining the input file for generating the trajectories of the pedestrians. The input file for JPScore needs to define a lot of variable including the number of pedestrians in different rooms as well as the final destination. After generating the simulation we can see that with the help of JPSvis. JPSvis will show the trajectories of the moving pedestrians inside the geometry. This generated trajectory file will be used by JPSreport to generate the value of different aspect of pedestrian movement such as velocity, density, flow etc. and then with the help of these data we can generate various plots to accomplish our objectives.

3.3 Software – Jupedsim

We used open source software named as Jupedsim for generating different kind of results with various components of it named as JPSeditor, JPSreport, JPSvis, and JPScore. We will try to explain these components along with their function and installation. Primary reason behind using open source software is that we can modify the basic library functions according to our requirements if needed and also it gives us the freedom to define the geometry and distributing pedestrians inside it unlike some other softwares. The primary goal of this software is to provide a tool for visualization and validation of different pedestrian related models. Primarily this is used as a tool for analysis of different evacuation scenarios but its applications can be extended to many other fields related to pedestrian movement. This software mainly has four modules which works together to give the intended results (see figure).

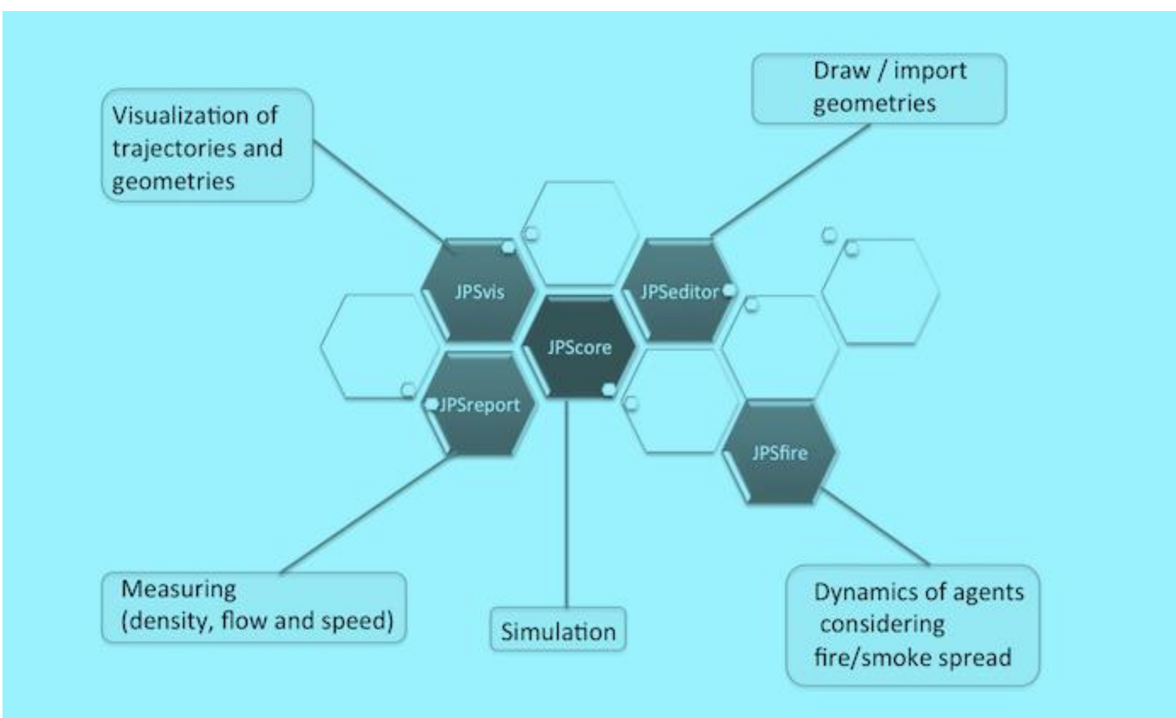

Figure 3.1: Basic organization of Jupedsim

(Source: https://www.jupedsim.org/jupedsim_introduction.html**)**

JPSfire module of this software is not used by us as this is specifically used for evacuation of buildings in case of fire.

JPSeditor: This is basically used for drawing the plan or geometry of building.

JPScore: This is for generating the trajectories of agents.

JPSvis: This is for visualization of trajectories generated by JPScore.

JPSreport: This module provides the results in terms of density, velocity flow etc.

3.4 Installation

For installation of these components in Windows we need to install an installer for visualization and then we have to download the zip directory of visualization. When we need to start the simulation we need to open the Windows PowerShell and with the help of JPScore samples we can start the simulation by writing the command as "*jpscore.exe ./plan3_ini.xml"*(see figure 2).

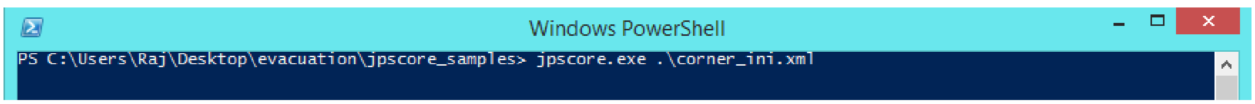

Figure 3.2: Command for starting simulation

When we press the enter key with this command, it will run the simulations for input file names as "corner_ini_ini.xml". When this simulation will complete it will generate a folder named as "Results" in same directory as of corner_ini.xml which contains the geometry file of corner, trajectory file of corner and it will have the same input file also. All these three files will be of xml format but when we try to generate the data with the help of JPSreport then we need the trajectory file in text format. So for generating the text file we need to do some changes in input file of corner about which we will talk in later sections. When the simulation gets PowerShell window will be like this:

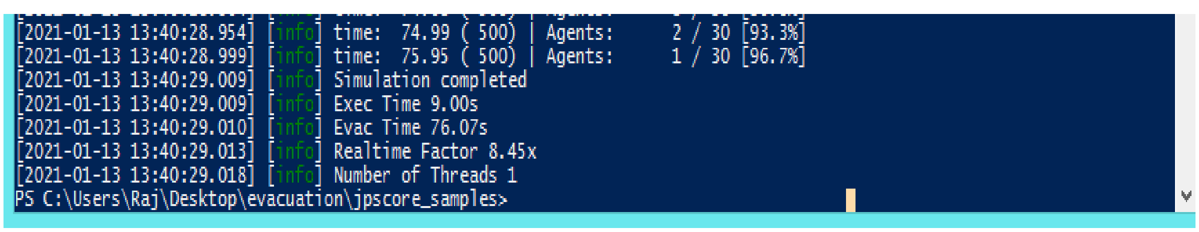

Figure 3.3: Simulation completion message

After completion of the simulation we can see the generated simulation with the help of JPSvis. It will show the trajectories of the pedestrians and time of evacuation of facility. We can see the simulation by following below given steps.

Step 1: open the JPSvis application

Step 2: choose the file for which you want to see the visualization.

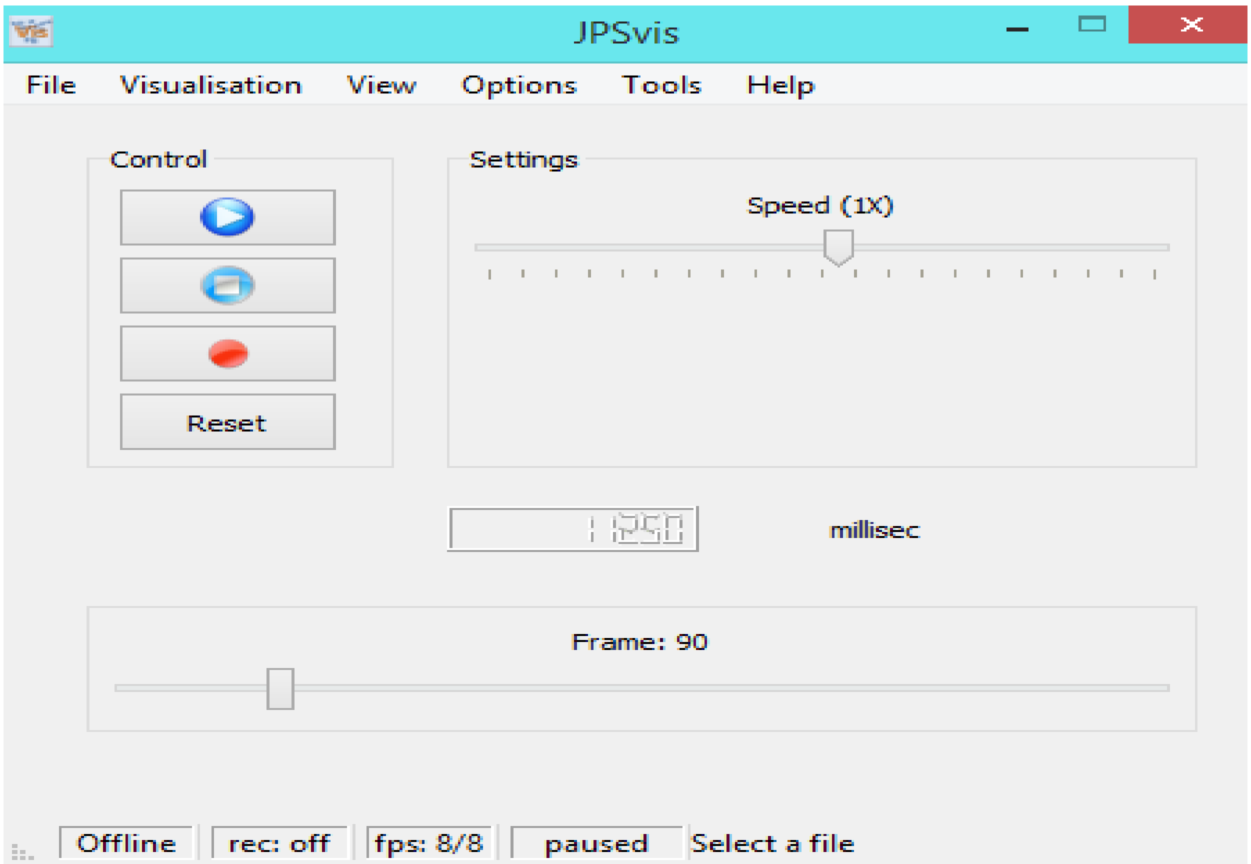

Figure 3.4: JPSvis application window

As we can see in above figure that we can choose a file form file for this but we have to keep in mind that it will take the xml format of trajectory file. The View button of the application window gives the different option regarding the visualization like whether we want to see the trajectories of agents or not, we want to see the agent id or not etc.

Step 3: when we select the file then an additional window will open which show the simulation. The window will be look like this:

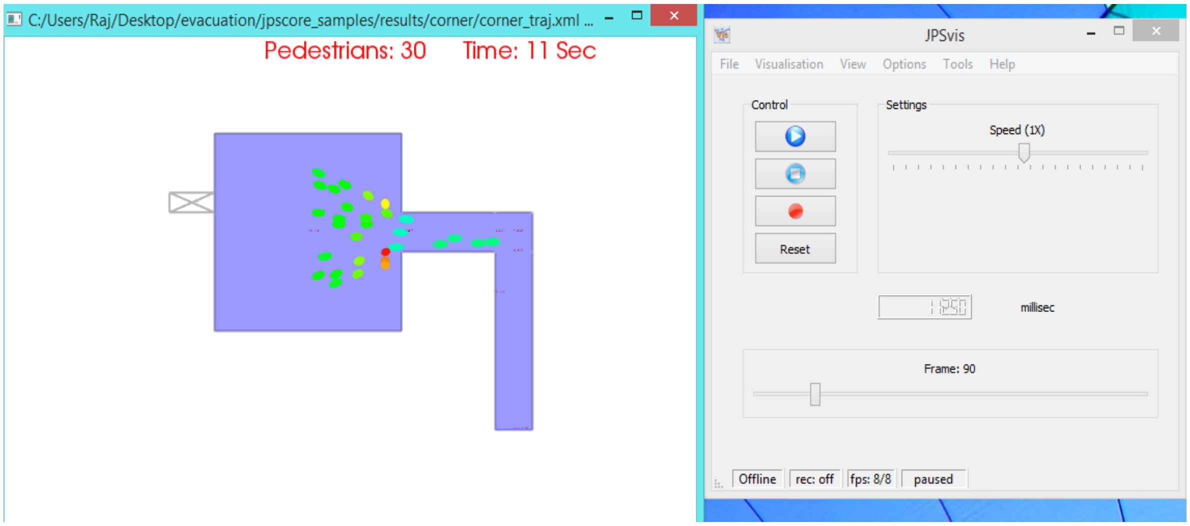

Figure 3.5: Visualization window

Now we are aware of the functioning of these modules, we need to look into the background process that is happening while generating these results, simulation and visualization. First of all we will be in need of a geometry file for which we are planning to generate the simulations; this file can be generated with the help of JPSeditor.

3.5 JPSeditor

This module is helpful in generating the geometry. Here we can draw the plan simply with the help of different tools given in the software (see figure) which allows us to draw the walls and doors. We need to save this drawing in form of rooms, category of rooms and doors for respective rooms. Doors here will be of two categories; first, crossings which will be indicator of having different sub rooms inside a room and agents will move freely out of these doors. Second, transitions which the door between two different rooms or between a room and outside. It has some other features which include drawing of line with the coordinate system; also we can define the final goals of the pedestrians where they will exit. Here simply we can write the xml file for geometry but that will cause some unnecessary errors while using JPSeditor as well as JPScore and JPSreport because this is still in developing stage and has some bugs. The important thing here is that after developing the geometry we should always check it with JPSvis for visualization to make sure it is correct. Because sometimes it is correct in JPSeditor but visualizer does not show the geometry.

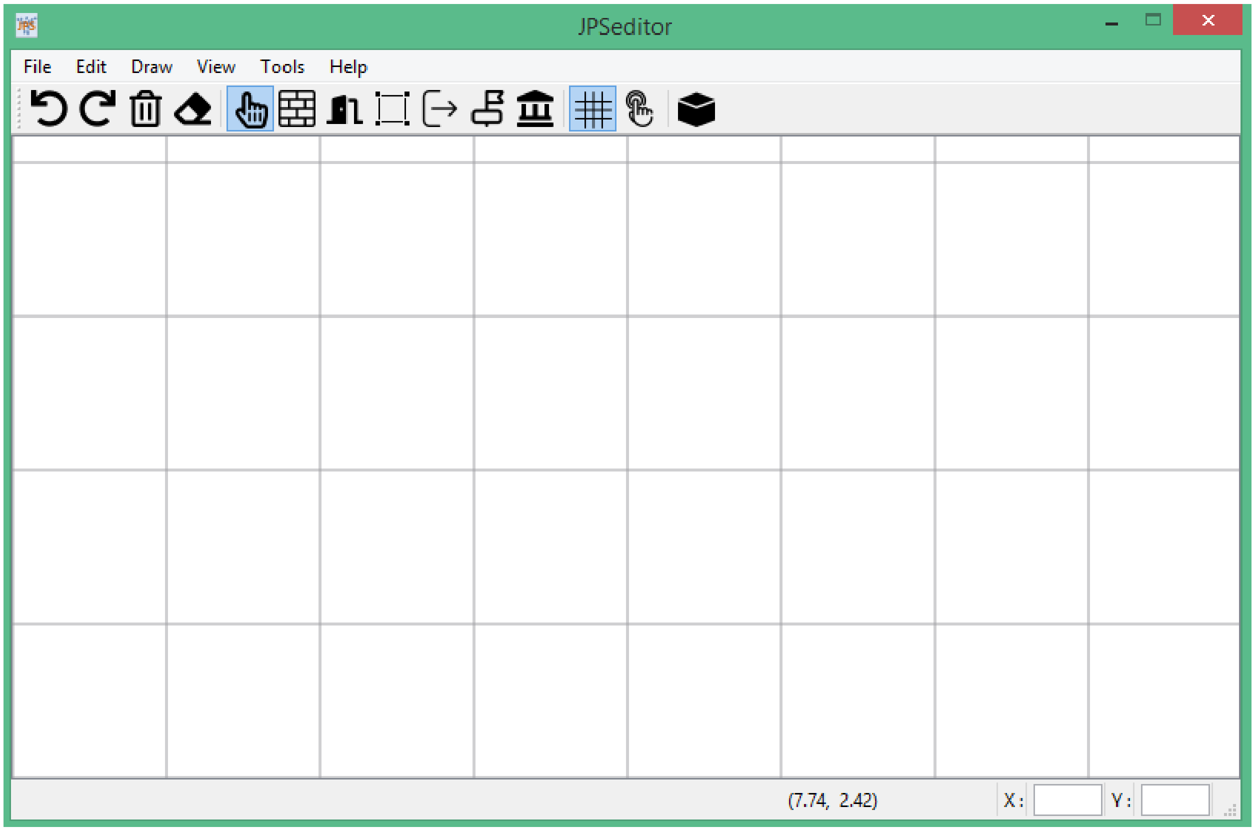

Figure 3.6: JPSeditor

The geometry file generated with this has xml format and looks like shown below. This file shows the code for single room only and it can be easily understandable that in similar manner we can define the file for any geometry.

```
<subroom id="2" caption="Room 2" class="Not specified" A_x="0" B_y="0" C_z="0">
    <polygon caption="wall">
        <vertex px="4" py="3.5"/>
        <vertex px="2" py="3.5"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="4" py="2.5"/>
        <vertex px="2" py="2.5"/>
    </polygon>
</subroom>
```

Figure 3.7: Sample of geometry file

In similar manners it has definition of crossings and transitions. After installation of these basic components of Jupedsim, it is ready to be used for simulations.

CHAPTER 4: ANALYSIS AND RESULTS

In previous chapter we tried to explain the working of this entire software and now it is time to do some analysis with help of different modules of Jupedsim. Here my work is related to analysis of pedestrian movement in new lecture hall complex of IIT Roorkee, for which we need to have the plans of different floor of lecture hall complex for generating the geometry in JPSeditor. We have generated the plan for ground floor and tried to get different simulation results with the help of that.

4.1 Generation of Geometry

With help of floor plan of new lecture hall complex we tried to generate the geometry of ground floor with the help of JPSeditor.

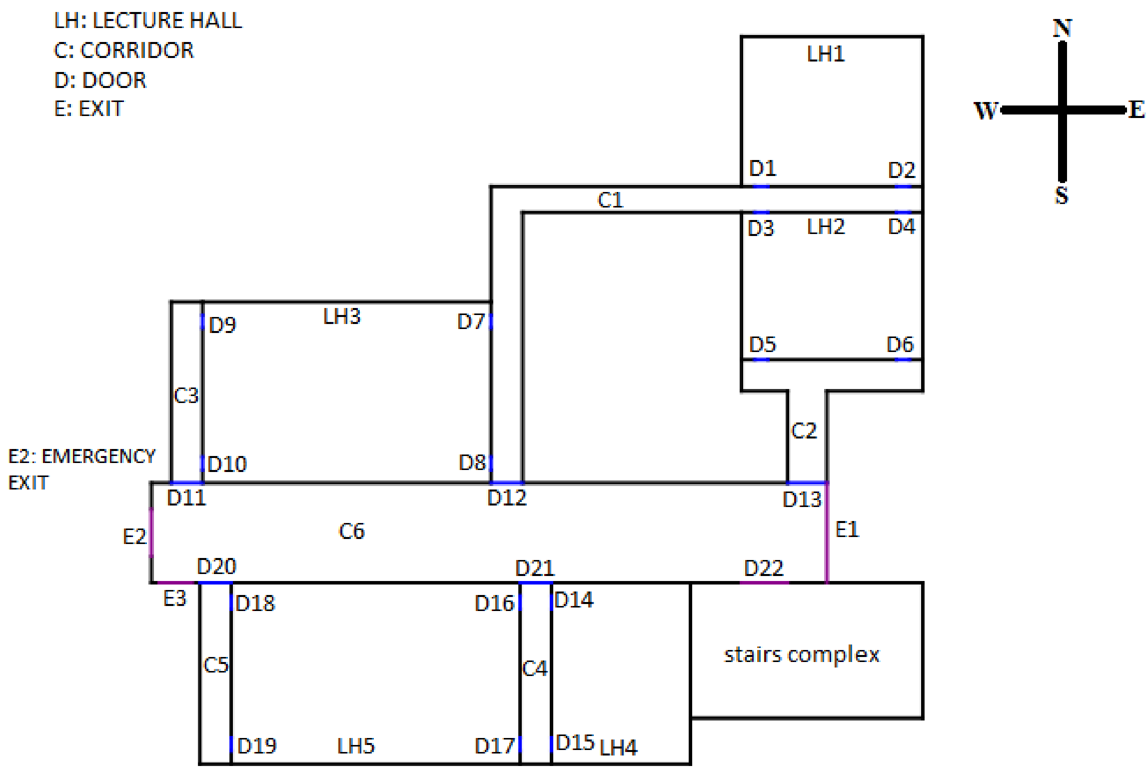

Figure 4.1: Ground floor plan

When we save the above file in JPSeditor it will generate an xml file for this geometry which we will use in visualization as well as in JPSreport. Now our next step after this will be to use the JPScore for simulation.

4.2 Simulation with JPScore

JPScore will generate the simulation for the geometry which we have created with the help of JPSeditor. For this we need to define an input file and it have many variables in it:

1. Header:

   It primarily consists of maximum simulation time definition, name and location of geometry file, name of output folder where we want to store simulated data under the name Results and trajectory file type which we want to generate. Syntax for trajectory file is as follows:

```
<trajectories format="text" fps="8">
<file location="plan4_traj.txt" />
</trajectories>
```

```
<trajectories format="xml-plain" fps="8">
<file location="plan4_traj.xml" />
</trajectories>
```

2. Routing and Goals:

   This part of input file defines the additional goals inside or outside of the geometry i.e. area or region where we want to send the pedestrian.

3. Agents:

   This part of input file gives the information regarding the number of agents (randomly distributed) in different rooms and we define this as shown below.

```
 <agents operational_model_id="3">
<agents_distribution>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="0" number="40" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="1" number="10" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="2" number="15" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="3" number="15" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="4" number="15" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="5" number="20" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="6" number="15" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="7" number="10" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="8" number="15" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="9" number="25" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="10" number="30" goal_id="-1" router_id="1"  pre_movement_mean="0"   pre_movement_sigma="0"/>
</agents_distribution>
</agents>
```

Figure 4.2: Number of Agents in rooms

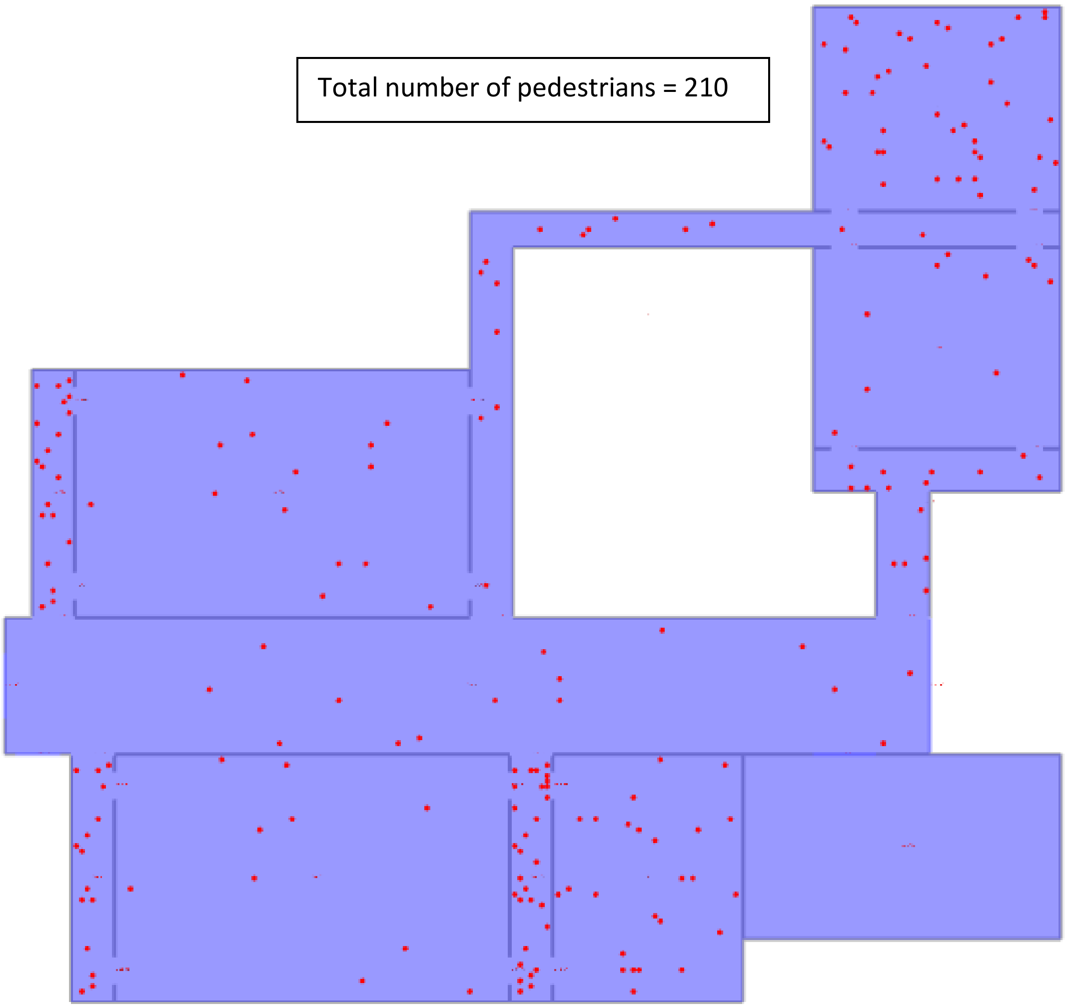

Figure 4.3: Distribution of agents in rooms

4. Operational Models:

   For generating the simulation we need to define the operational models in input file. One of them is Generalized Centrifugal Force Model and another one is collision free speed model. Both these have different parameters for pedestrians which we can change on the basis of our demand. The parameters of these models will decide the various aspects of the movement such as the spacing between pedestrians etc.

5. Routers:

   Last thing in the input file is to define the router which we are using for simulation. It has three available option as Floorfield global shortest, global shortest and quickest.

4.3 Visualization with JPSvis

After generation of the simulations we can see that with the help of JPSvis. We can see the geometry as well as the trajectory with the help of this. When I run these files first with JPScore and then with JPSvis, I get the simulation as follows:

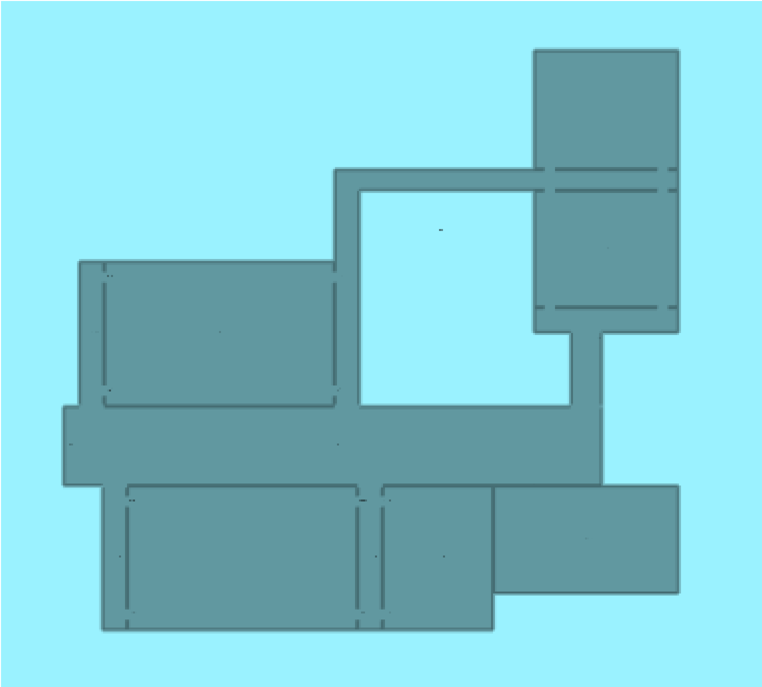

Figure 4.4: Geometry visualized with JPSvis

Now when we run the simulation with the help of JPSvis we got the movement of pedestrians through these rooms and corridors towards the exit of the lecture hall complex and it will look like the below shown picture. As we have mentioned earlier that there will be 210 pedestrians with numbers varying in different rooms and corridors. The simulation will start at t = 0 seconds with all the pedestrians inside the building and it will end at t = 46 seconds with zero pedestrians inside the building. We can see the trajectories of the pedestrians at different time values such 5 seconds, 10 seconds etc. also there will be different colors of trajectories on the basis if the speed and density of the pedestrians which will help in understanding the movement better with respect to congestion and free flow of pedestrians.

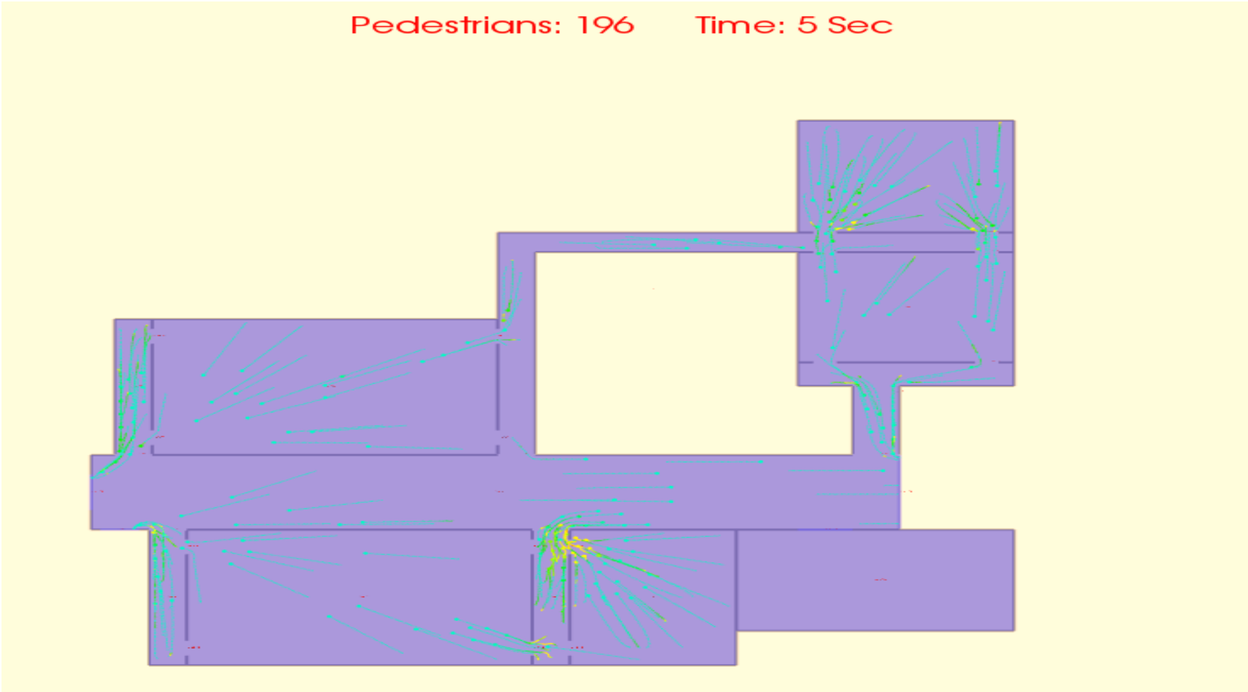

Figure 4.5: Trajectory visualization with JPSvis at 5 second

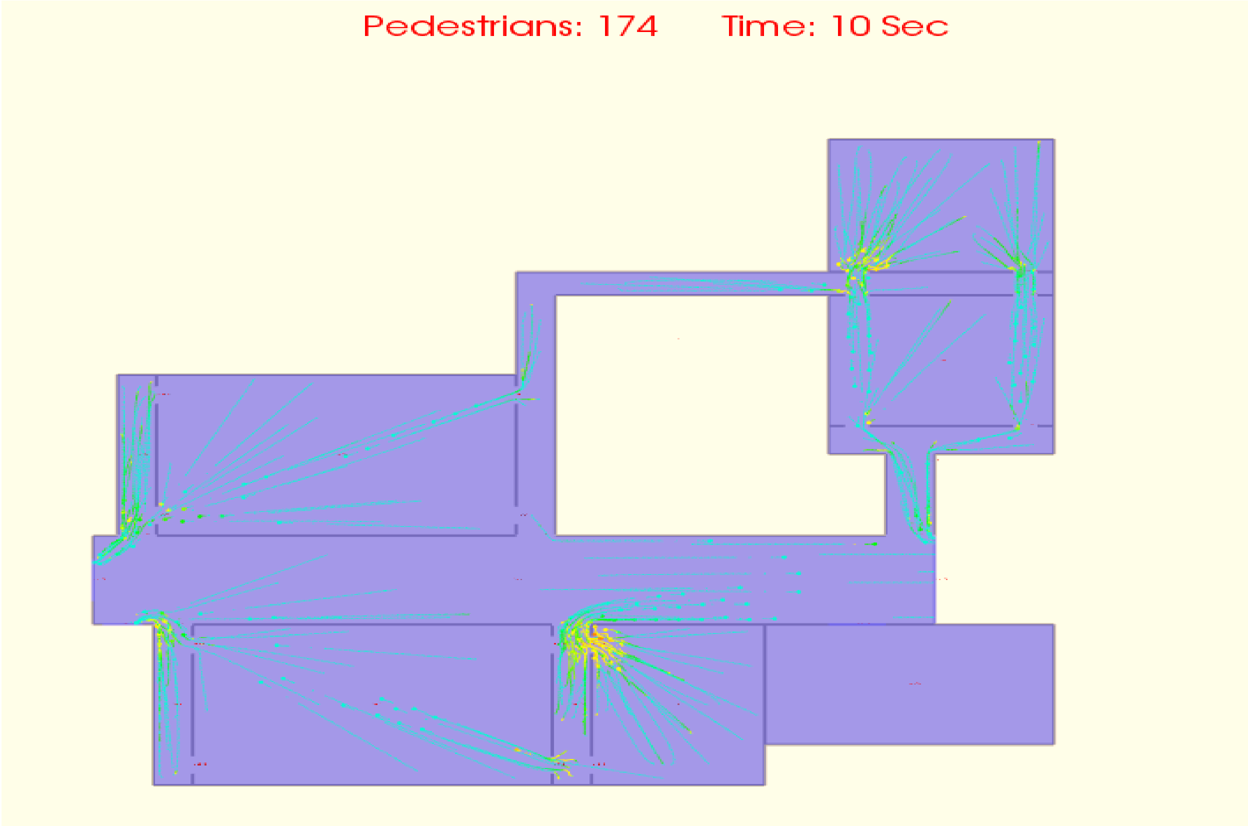

Figure 4.6: Trajectory visualization with JPSvis at 10 second

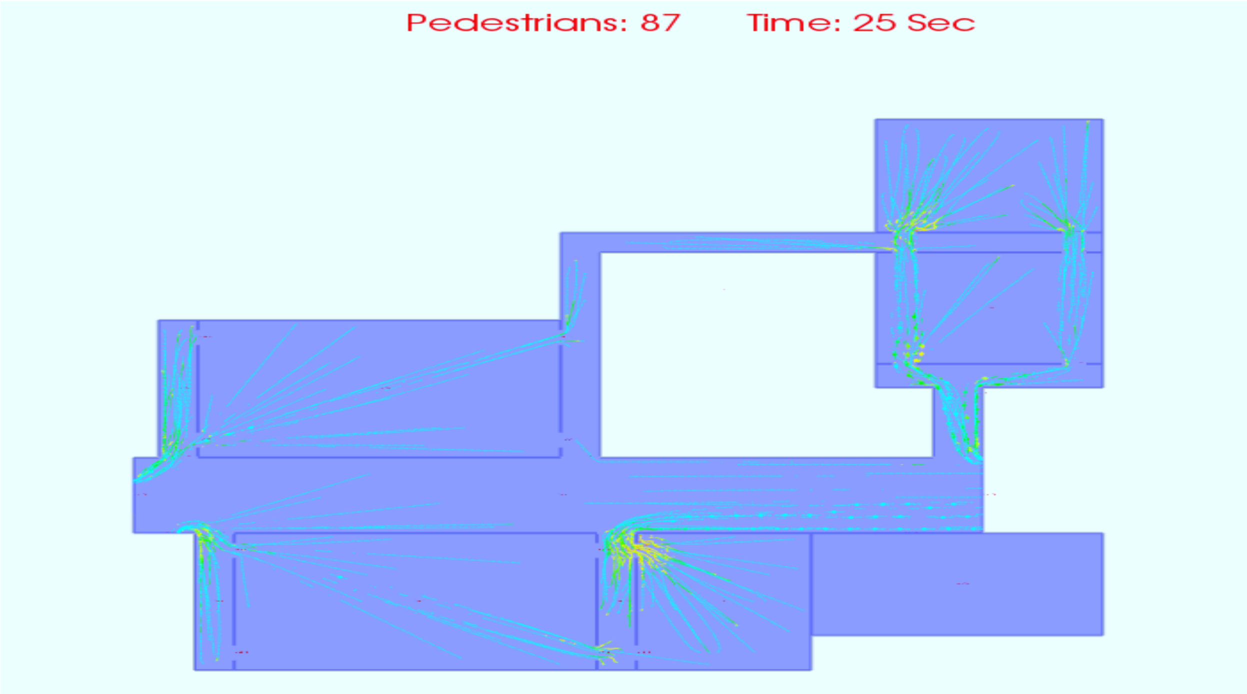

Figure 4.7: Trajectory visualization with JPSvis at 25 second

Figure 4.8: Trajectory visualization with JPSvis at 46 second

Above four pictures shows the trajectories of agents at different time of evacuation. As we can see that as the time increases there is a color change at different doors that is because of the pedestrian jam at particular door. So at this time our chosen operational model in input file plays an important role. Generally the models suggest two types of paths; first one is shortest and second one is the quickest. It is not necessary that shortest path is quickest path because of jamming conditions agents have to wait longer at doors which may exceed sometime to the time taken in longer path. Thus this software basically analyzes at present situation and suggests the best path according to that.

4.4 Analysis with JPSreport:

After seeing the simulation we need to find the data for various variables such as velocity, density, flow etc. JPSreport is similar to JPScore as here also we need an input file along with geometry file and trajectory file in text format. Trajectory file here needed is in text format and generated by JPScore, geometry file is generated with JPSeditor while input file is defined by us.

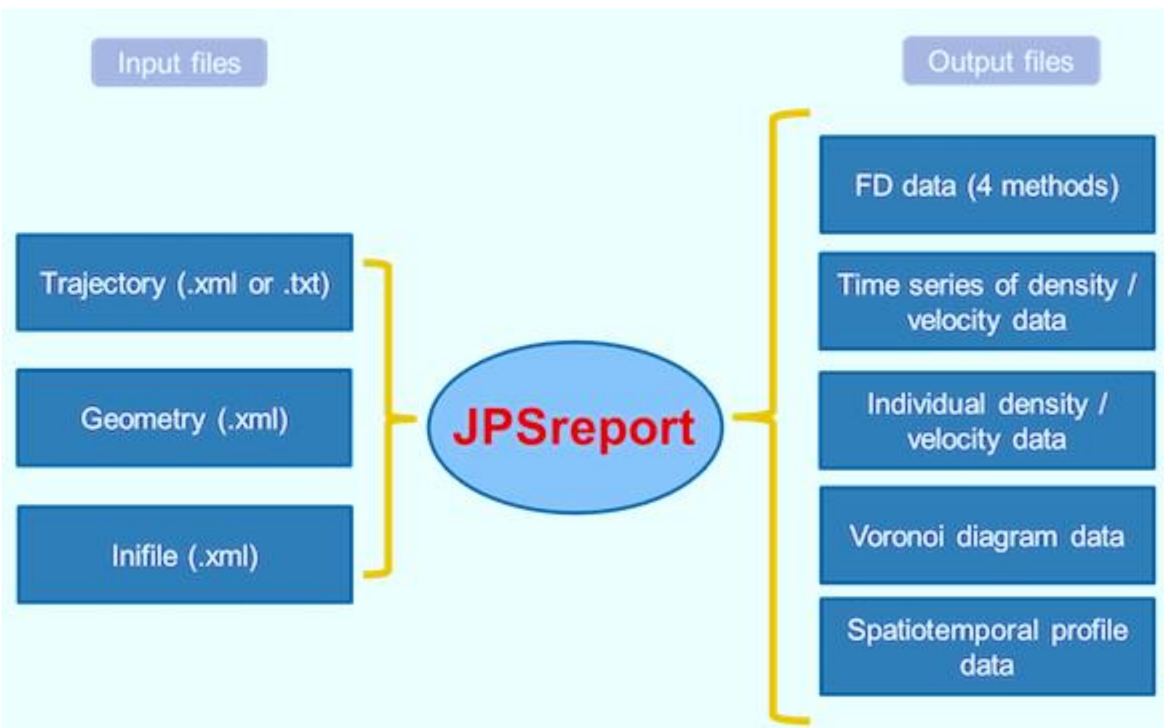

Figure 4.9: JPS report functioning

(Source: https://www.jupedsim.org/jpsreport_introduction.html)

Input file of the JPSreport has many components which affects the results. It includes header, logfile, geometry file we need to pass in there, also it needs the location and name of output folder where we want to store our data, trajectory file in text format is required, we also need to define the measurement area where we want to do our analysis. The area can be defined in two ways; First one is the bounding box and second one is the reference line at we want to take the observations. Lastly we need to define our method of analysis about which we can talk briefly here; there are broadly four methods out of which for our analysis Method A and Method D will be useful. Since the main focus of the study is to determine the flow, velocity and density of the pedestrians, Method A will give the flow and velocity of pedestrians in certain time interval while Method D will give the relations between density and velocity. Both of the methods are defined below:

- Method A: This method is used to analyze the steady state. It will give the cumulative number of pedestrians at a reference line along with flow rate (J) and mean velocity (V).

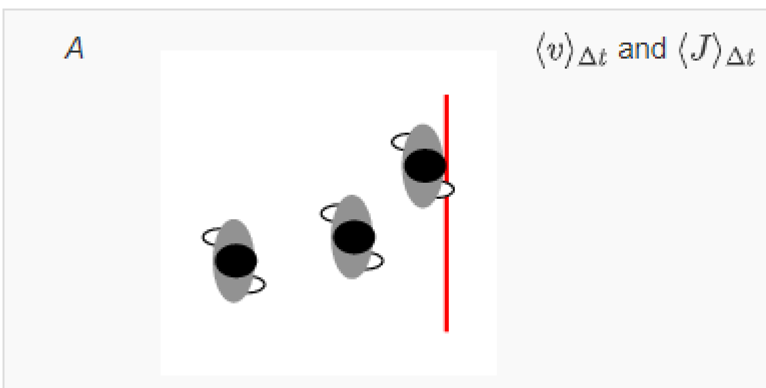

Figure 4.10: Method A

(Source: https://www.jupedsim.org/jpsreport_inifile.html)

$$\langle J \rangle_{\Delta t} = \frac{N^{\Delta t}}{t_N^{\Delta t} - t_1^{\Delta t}} \qquad \text{and} \qquad \langle v \rangle_{\Delta t} = \frac{1}{N^{\Delta t}} \sum_{i=1}^{N^{\Delta t}} v_i(t),$$

$$v_i(t) = \frac{\vec{x}_i(t + \Delta t'/2) - \vec{x}_i(t - \Delta t'/2))}{\Delta t'}$$

Where N is the number of pedestrians passing a particular section in time interval Δt and $V_i(t)$ is the instantaneous velocity of pedestrians in small time interval Δt', which is used in calculation of mean velocity over time interval Δt.

For measuring the flow and velocity, two sections were selected. First one is at the door of the lecture hall 1 (LH1) and second one at the main exit gate of the building to compare the velocity and flow at two locations. For the given distribution of pedestrians following data were obtained:

Table 4.1: Flow rate and mean velocity for section at door of lecture hall 1

frame	Flow rate (1/s)	Mean velocity(m/s)
10	1.600	1.173
20	2.286	0.837
30	1.333	1.041
40	1.600	0.654
50	2.000	0.799
60	1.778	0.864
70	2.462	0.803
80	2.000	0.665
90	2.667	0.764
100	1.231	0.625
110	1.778	0.547

Table 4.2: Flow rate and mean velocity for section at main exit

frame	Flow rate (1/s)	Mean velocity(m/s)
10	1.333	1.089
20	0.800	0.737
30	0.941	1.037

40	1.778	1.085
50	2.000	1.095
60	1.600	0.877
70	1.143	1.058
80	1.778	0.69
90	0.800	1.08
100	0.571	1.181
110	0.889	0.645
120	0.500	1.182
130	1.600	0.958
140	1.333	1.042
150	1.455	0.963
160	1.778	0.737
170	1.600	1.021
180	1.778	0.773
190	1.714	1.140
200	2.286	0.795
210	2.182	0.529
220	2.667	0.841
230	1.778	0.803
240	2.182	0.869
250	2.000	0.986
260	2.400	0.944
270	3.000	0.930
280	2.182	1.133
290	1.846	0.639

300	2.286	0.000
310	1.231	0.569
320	2.400	0.442

Now on the basis of above data, flow and mean velocity comparison plots were drawn as shown below:

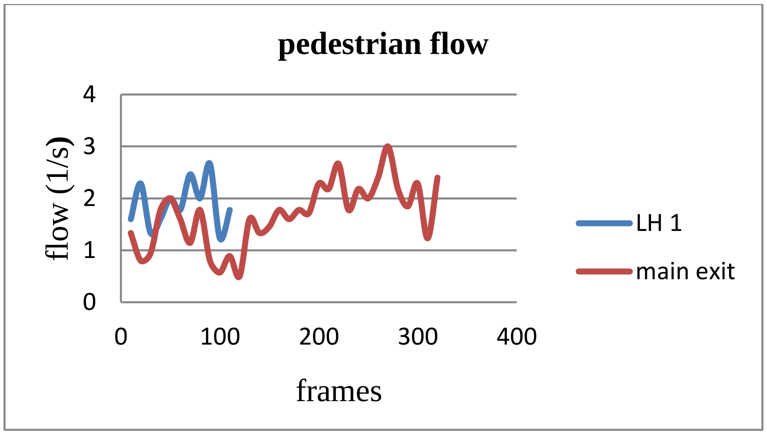

Figure 4.11: Pedestrian flow comparison

Here we can see very clearly that flow is more for LH1 than the main exit. This is because initially very few pedestrians were there at main exit and LH1 was having 40 people and were randomly distributed in the lecture hall. So in early stage they move fast and contributed to higher flow rate. In later stage when most of the pedestrians were at main exit the flow is high but not much higher because of the congestion.

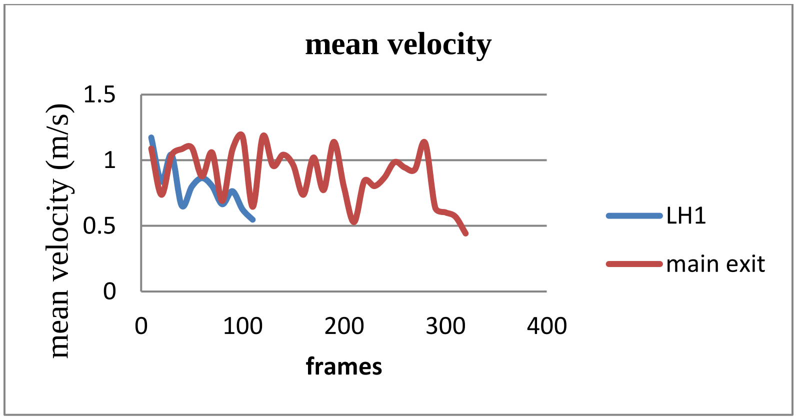

Figure 4.12: Mean velocity comparison

From the above comparison we can see that mean velocity of the pedestrians is comparable initially as the distribution is random and they will move freely in start. But it started to decline in case of LH1 due to congestion in front of the door but at the same time the velocity is almost same to initial velocity in case of the main exit. This is due to the fact that pedestrians have not reached to the main exit to cause congestion and situation is same as initial situation because the size of the main exit door is bigger than the LH1 door.

- Method D: this method can be used for steady state as well as for time series analysis. This will give the classical velocity as well as voronoi velocity along with classical density and voronoi density respectively.

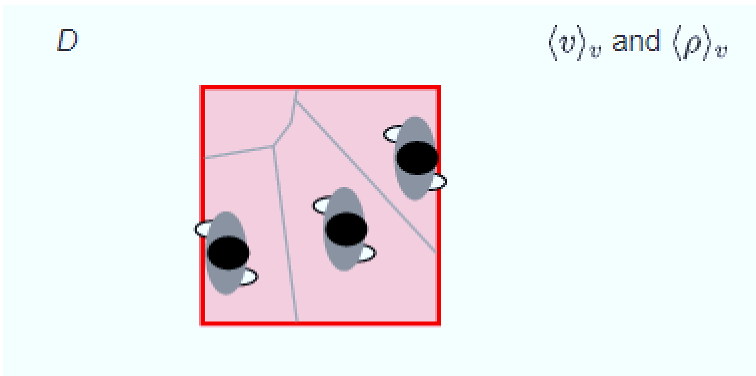

Figure 4.13: Method D

(Source: https://www.jupedsim.org/jpsreport_inifile.html)

Voronoi density $(\rho)_v$ for particular measurement area can be defined as:

$$\langle \rho \rangle_v = \frac{\iint \rho_{xy} dxdy}{b_{\text{cor}} \cdot \Delta x}$$

Voronoi velocity $(V)_v$ is defined as:

$$\langle v \rangle_v = \frac{\iint v_{xy} dxdy}{b_{\text{cor}} \cdot \Delta x}$$

Where

$$\rho_{xy} = 1/A_i \quad \text{and} \quad v_{xy} = v_i(t) \qquad \text{if}(x, y) \in A_i,$$

A_i = Area of the voronoi cells

The arithmetic velocity of the pedestrians will be the average of the instantaneous velocities of the pedestrians.

To perform the analysis with the help of Method D we need to define a bounding box of rectangular or square shape. So the software will do the analysis of the pedestrians inside the box. For this purpose in this study two areas of different dimensions at two different locations are selected to compare the results at two locations.

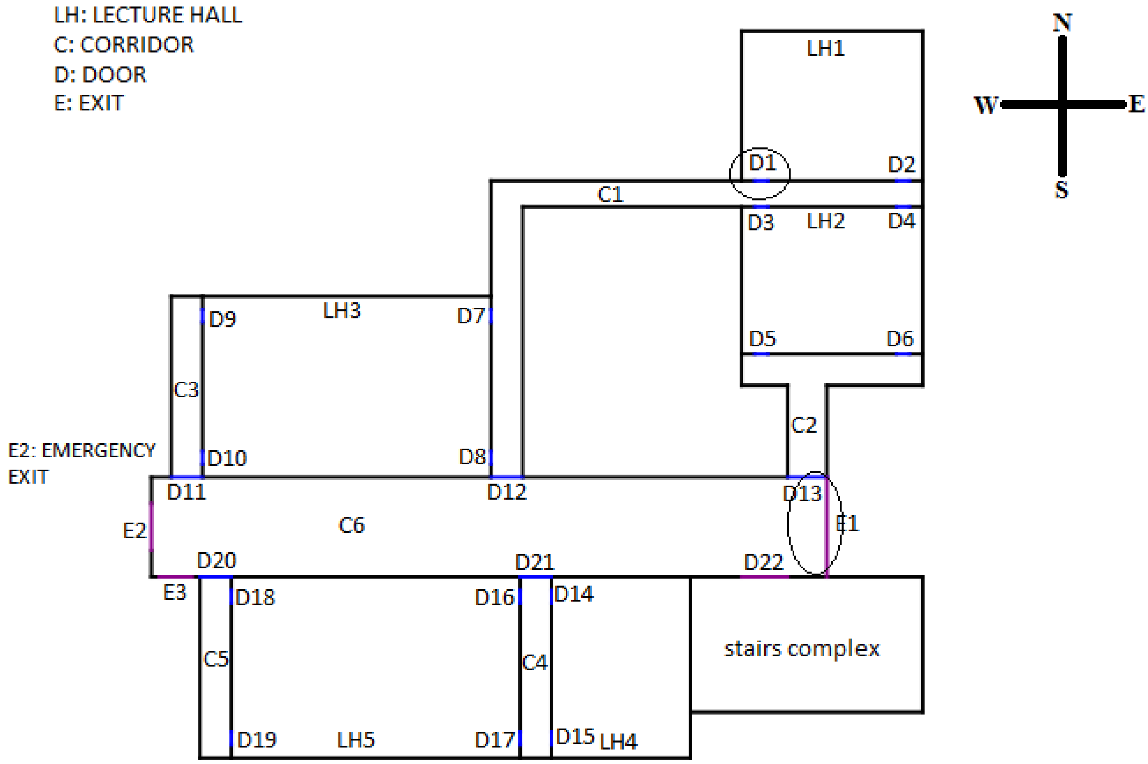

Figure 4.14: Plan of ground floor with marked analysis area

The first location for the area is in front of the door D1 of LH1 and the second location is in the front of main exit E1. Since area at both of these locations is of two different sizes:

A_{LH}: large area in front of D1 (7.6x7.0)

a_{LH}: small area in front of D1 (7.6x1.0)

A_{ME}: large area in front of E1 (7.6x7.0)

a_{ME}: small area in front of E1 (7.6x1.0)

When the analysis was done with Method D, JPSreport will give the values of the density and velocity corresponding to each frame of simulation. This data is plotted with the help of Jupyterlab for the comparison of density and velocity of pedestrians at two different locations in two different sizes of bounding box.

(A) Comparison of the density v/s frame and velocity v/s frame plots for area of same size but different locations:

The figure below shows the comparison of density v/s frame and Velocity v/s frame for large area and small area in front of lecture hall door and in front of main exit.

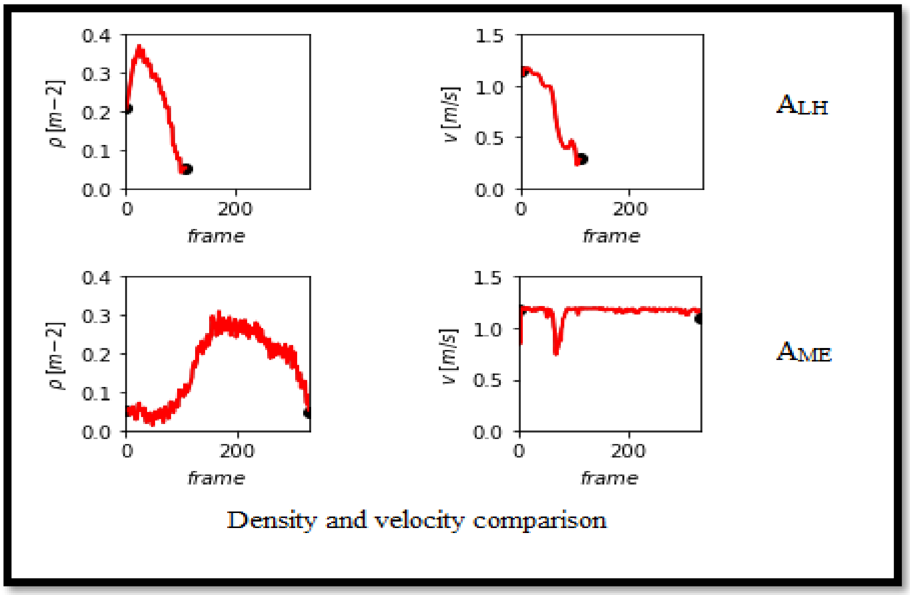

Figure 4.15: Density and Velocity comparison for large area size

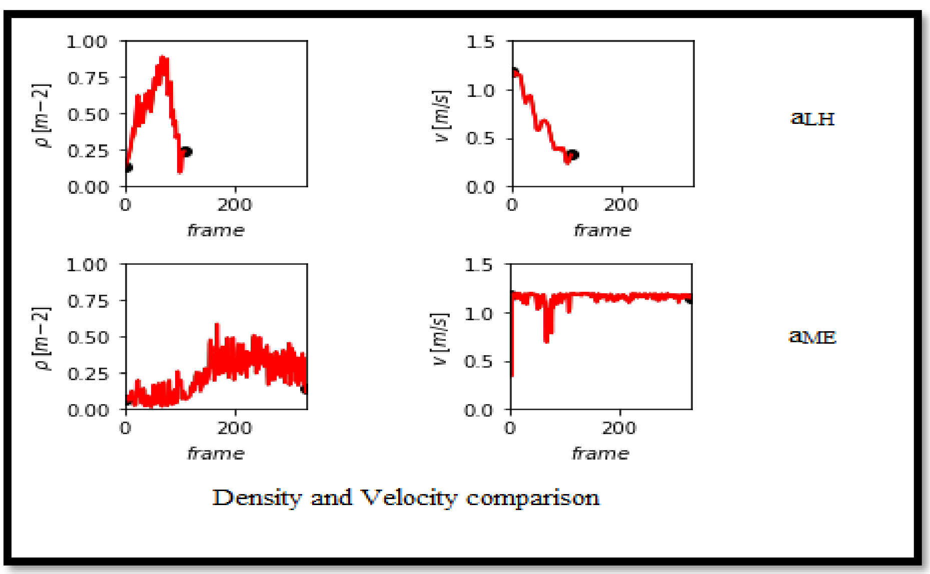

Figure 4.16: Density and Velocity comparison for small area

When we look at the plots of density and velocity with respect to frames which is indirectly is the measure of the time, the plots of Lecture Halls are found to be running for 110 frames only.

This indicates that the simulation of the pedestrians in lecture hall ended at that time which is not the case for main exit area. Value of density first increases in case of both small and large area of lecture halls and then decreases. The increase is attributed to the rushing of pedestrians towards the gate and after reaching the maximum value it started to decrease as they are moving out of the analysis area. At the time of the minimum density in lecture hall it has been noted that the main exit has the maximum density because pedestrians coming different lecture halls have reached at the main exit. One more contrasting thing is that the increasing and decrease in value of the density is sharp in case of the lecture hall but there is gradual increase and decrease in the value because of the bigger size of the door and also the pedestrians are reaching at gate at slow rate because of the variable distance from the gate.

The velocity value in case of both the areas of lecture halls is continuously decreasing as they are moving towards the exit, congestion is happening simultaneously and this means less space to move which ultimately results in the decrease of the velocity. But interesting thing here is that the velocity value in case of the both areas in front of main exit is almost constant. This is because the most of the pedestrians are reaching at the gate in there free flow speed after passing the congestion of their respective door of lecture halls. Also they are not reaching all at a time as the distance of the lecture halls is different from the main exit. One more factor which is contributing is the large door size of the main exit because of which a strange behavior of queue formation is observed.

(B) Comparison of the density v/s frame and velocity v/s frame plots for area of different size but same locations:

Here in figures below there is the comparison of Density v/s frame and Velocity v/s frame plots for the same location by choosing different analysis area. The density plots show that the value of density is higher in case of the small area at both the locations than the large area because the area is near to door and there is the situation of congestion always. Ratio of maximum, density in large area to small area is little bit more than 2 for lecture hall but the same is less for main exit .Also the value of density is varying significantly in case of the small area as compared to the large area because variation in number of pedestrian is always significant in small area and slight change will affect the density significantly in case of small area.

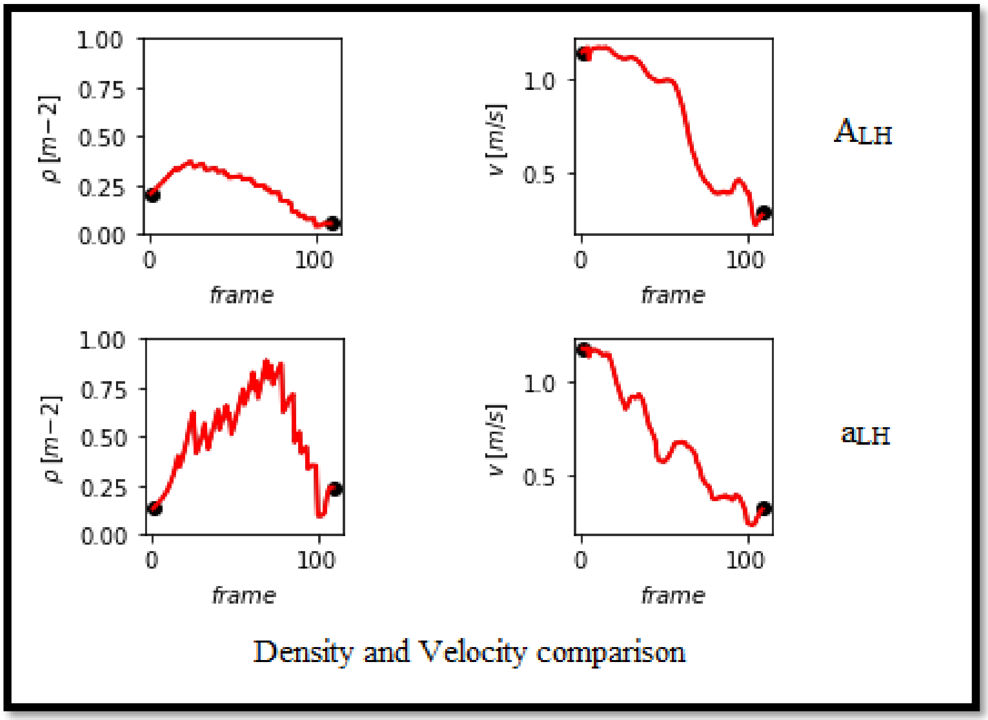

Figure 4.17: Density and Velocity comparison at Lecture Hall

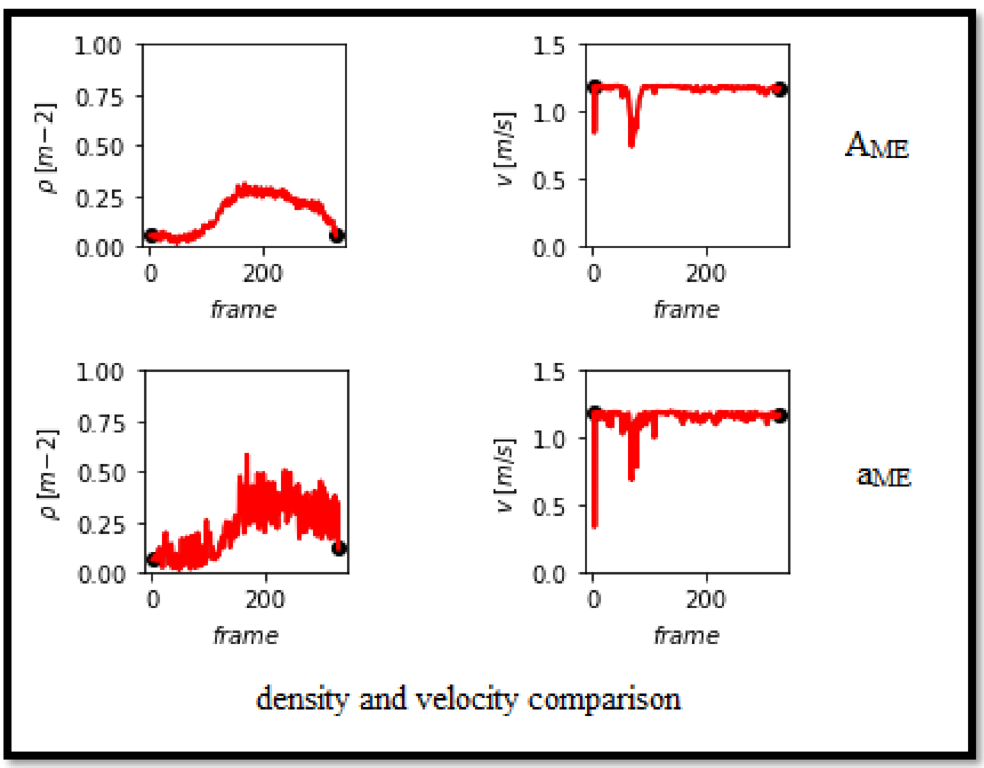

Figure 4.18: Density and Velocity comparison at Main Exit

In case of velocity variation as per above graphs, he value is decreasing always for lecture hall for both areas and this is because of the congestion in front of the small door D1. The velocity variation for main exit areas is almost constant for both the areas because of the bigger door size and also there is no rush in the pedestrians as they are just moving in a queue.

4.5 Evacuation time analysis

Evacuation time is basically the time interval between the time when pedestrians become aware of any significantly hazardous activity inside the facility and start their movement to the time at which they reached at a safe place. This is significantly important in designing the evacuation plan of the building in case of emergency situations such as fire etc. Evacuation time of facility depends on many factors including the geometry of the building, type of emergency, behavior of the pedestrians and distribution of the pedestrians along age and gender. In present study we try to explore the dependence of number pedestrians inside the facility. For this we ran a number of scenarios by changing the number pedestrians and secondly keeping the number of pedestrians constant and just distributing differently.

(A) Changing the number of pedestrians inside the building

Table 4.3: Number of pedestrians in rooms and corridors

LH1	**LH2**	**LH3**	**C1**	**C2**	**C3**	**C4**	**LH4**	**C5**	**LH5**	**C6**	**TOTAL**	**TIME(s)**
40	10	15	15	15	20	15	10	15	25	30	210	46
60	50	80	0	0	0	0	80	0	50	0	320	55
70	60	100	0	0	0	0	100	0	60	0	390	61
80	70	120	0	0	0	0	120	0	70	0	460	67
90	80	140	0	0	0	0	140	0	80	0	530	71
100	90	160	0	0	0	0	160	0	90	0	600	79
110	100	180	0	0	0	0	180	0	100	0	670	85
120	110	200	0	0	0	0	200	0	110	0	740	92
130	120	220	0	0	0	0	220	0	120	0	810	100
140	130	240	0	0	0	0	240	0	130	0	880	105
155	155	256	0	0	0	0	256	0	144	0	966	114
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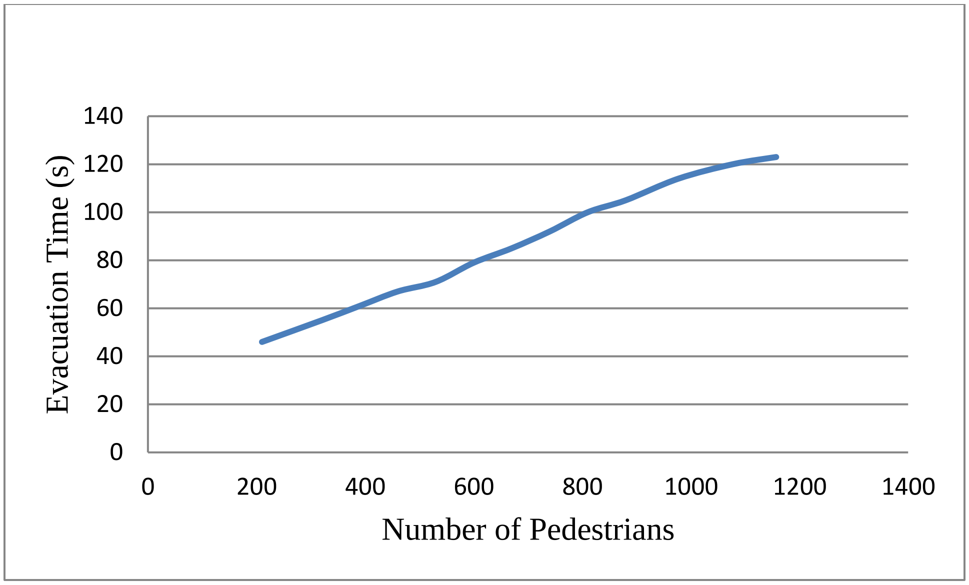

Figure 4.19: Variation of time with number of pedestrians

The table above shows the number of pedestrians in different lecture halls and corridors in a particular trial. The number of pedestrians keeps on increasing initially in the lecture halls and when lecture halls reached to the maximum capacity, some pedestrians were been introduced in corridors also. The plot shows that the evacuation time will keep on increasing as we increase the number of pedestrians inside the facility and this is almost linearly dependent on the number of pedestrians.

(B) Changing the distribution of the pedestrians with same number of pedestrians

Table 4.4: Number of pedestrians in rooms and corridors

LH1	**LH2**	**LH3**	**C1**	**C2**	**C3**	**C4**	**LH4**	**C5**	**LH5**	**C6**	**TOTAL**	**TIME(s)**
90	80	140	0	0	0	0	140	0	80	0	530	71
100	70	120	0	0	0	0	150	0	90	0	530	76
110	60	100	0	0	0	0	160	0	100	0	530	79
120	50	80	0	0	0	0	170	0	110	0	530	82
130	40	60	0	0	0	0	180	0	120	0	530	86
155	15	20	0	0	0	0	200	0	140	0	530	93
80	90	160	0	0	0	0	130	0	70	0	530	70
60	50	100	30	15	15	50	110	20	60	20	530	66
70	60	120	20	10	10	30	120	10	70	10	530	66

The table above shows the distribution of the pedestrians inside the building with keeping number of pedestrian constant at 530. It is easily evident that the evacuation time is changing even after the total number of pedestrians is constant. In upper rows, the number of pedestrians is higher in rooms which are away from the main exit of the building so the time is increasing but in lower rows when the numbers are low in rooms and there is significant number of pedestrians in corridors, evacuation time is less. But if we keep increasing the number of the pedestrian in corridors the evacuation time started to increase again. This happens because the more number of pedestrians in corridors causing the chaos and hindering the movement of pedestrians coming out of the rooms and ultimately resulting in the congestion. There is one more trend is that even if the room is near to exit and it is reaching to its maximum capacity, its evacuation time will be higher than the room which is away from the exit with less number of pedestrians. This is because in the full room pedestrians will not be able to move properly and cause congestion type of situation in start itself.

CHAPTER 5: CONCLUSIONS AND DISCUSSIONS

This chapter basically deals with the conclusions of the work have been done so far and the future work which can be done to improve the understanding of the pedestrians movement. In present study the purpose was to study the movement of the pedestrians inside the building which has been done with the help of simulation software Jupedsim by creating the geometry of the ground floor of the building and then simulating various scenarios and analyzing those scenarios in order to get the idea of pedestrian flow characteristics. Also the effect of the geometry of the structure on pedestrian movement has been studied.

5.1 Conclusions and Recommendations

The analysis of pedestrian movement in New Lecture Hall complex of IIT Roorkee has been done with the help of simulation software Jupedsim. The reviewed literature related to the topic gave us the fair idea that the movement of the pedestrians will depends on many factors related to the physical structure of the building, behavior of the pedestrians, type of emergency and distribution of pedestrians. Physical structure of the building counts for the size of the rooms and corridors, size of doors and the movement situations such as movement through the bottleneck or around the corner. Behavior of pedestrians is very subjective and it is affected by the type of emergency as well as by the surrounding environment along with the age and gender distribution of the pedestrians. From the running simulations on the geometry of the ground floor it was evident that there was congestion type of situation occurs when pedestrian move around the corner to exit the facility thus it is advisable to provide the exit such that there is no corner or bottleneck kind of situation just before it.

Analysis of density and velocity of pedestrians in a particular area and across the section has some significant results. One of the important things to understand is that pedestrian load is not similar everywhere in the geometry or even inside a room because during evacuation process the natural tendency is to move towards the door. Thus the critical locations will be around the doors of the rooms and exits of the building. When analysis is done it is concluded that in front of the door of the lecture hall, density increases initially and then it decreases to its minimum but velocity shows the decreasing trends but in case of the larger door size or main exit of the building, density has the maximum value around the time when it is minimum in the lecture hall and the velocity of pedestrians is almost constant. The value of density is much higher in front of small door as compared to the main exit because of the availability of more space in case of main exit.

Pedestrian flow across a section in case of small door is higher initially than the bigger door at given point of time but the mean velocity across the section is higher in case of the bigger door or main exit of the building. Another is that the average velocity near the doors is less and density will be higher near the doors as compared to the open space movement.

Evacuation time of the building is proportional to the number of pedestrians inside and it will keep on increasing as the number of pedestrian increases. It also depends on the distribution of the pedestrians inside the geometry. For constant number of pedestrians, if more number of pedestrians is in the rooms which are away from the main exit, evacuation time will be more. This also happens if we increase the number of pedestrians in the corridor as they will hinder the movement of pedestrians coming out of the rooms. Thus while designing the facility it should be keep in mind that higher capacity rooms should be kept near to the main exit and for the rooms away from the main exit, the corridor size should be proper which allows the smooth movement of the pedestrians in case of emergency.

5.2 Way Forward

The present study of pedestrian movement inside the building is based on the local shortest path available to pedestrians for accessing the exit of the facility. There can be two more ways of doing it by applying the condition of global shortest path and quickest path separately. The results can be useful in determining the evacuation plan of the geometry. One more thing is that there is a simple queue formation is happening when pedestrians are moving out of the facility which is bit surprising and at odd to the general perception of chaos at the door. So this can be investigated further experimentally or by analyzing the real world condition. The simulations here generated are for emergency situations and the results from this study should be compared with normal situation in order to get the better idea for the comparison of behavior of pedestrians under above mentioned circumstances.

The present study does not include the effect of the pedestrian distribution across gender and age, so this aspect can also be investigated further. The parameters of the generalized centrifugal force model are not similar for every kind of situation and thus it can be investigated further that how much they affect the simulation and analysis of pedestrian movement.

APPENDIX

1. Geometry file definition for ground floor


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        <vertex px="94.3" py="12.1"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="94.3" py="22.4"/>
        <vertex px="94.3" py="12.1"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="83.7" py="19.9"/>
        <vertex px="83.7" py="11.1"/>
    </polygon>
</subroom>
<subroom id="10" caption="Room 11" class="Corridor" A_x="0" B_y="0" C_z="0">
    <polygon caption="wall">
        <vertex px="81.3" py="8.6"/>
        <vertex px="83.7" py="8.6"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="81.3" py="22.4"/>
        <vertex px="81.3" py="21.4"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="81.3" py="8.6"/>
        <vertex px="81.3" py="9.6"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="83.7" py="8.6"/>
        <vertex px="83.7" py="9.6"/>
    </polygon>
    <polygon caption="wall">
        <vertex px="83.7" py="21.4"/>
```

```
      <vertex px="83.7" py="22.4"/>
    </polygon>
    <polygon caption="wall">
      <vertex px="81.3" py="19.9"/>
      <vertex px="81.3" py="11.1"/>
    </polygon>
    <polygon caption="wall">
      <vertex px="83.7" py="19.9"/>
      <vertex px="83.7" py="11.1"/>
    </polygon>
  </subroom>
  <crossings>
    <crossing id="0" subroom1_id="4" subroom2_id="6">
      <vertex px="101.7" py="30"/>
      <vertex px="104.7" py="30"/>
    </crossing>
    <crossing id="1" subroom1_id="3" subroom2_id="6">
      <vertex px="79.1" py="30"/>
      <vertex px="81.5" py="30"/>
    </crossing>
    <crossing id="2" subroom1_id="5" subroom2_id="6">
      <vertex px="54.7" py="30"/>
      <vertex px="57.1" py="30"/>
    </crossing>
    <crossing id="3" subroom1_id="8" subroom2_id="6">
      <vertex px="56.9" py="22.4"/>
      <vertex px="59.3" py="22.4"/>
    </crossing>
    <crossing id="4" subroom1_id="10" subroom2_id="6">
      <vertex px="81.3" py="22.4"/>
      <vertex px="83.7" py="22.4"/>
```

```
</crossing>
<crossing id="5" subroom1_id="0" subroom2_id="3">
    <vertex px="99.2" py="52.6"/>
    <vertex px="100.7" py="52.6"/>
</crossing>
<crossing id="6" subroom1_id="0" subroom2_id="3">
    <vertex px="111" py="52.6"/>
    <vertex px="109.5" py="52.6"/>
</crossing>
<crossing id="7" subroom1_id="1" subroom2_id="3">
    <vertex px="99.2" py="50.6"/>
    <vertex px="100.7" py="50.6"/>
</crossing>
<crossing id="8" subroom1_id="1" subroom2_id="3">
    <vertex px="111" py="50.6"/>
    <vertex px="109.5" py="50.6"/>
</crossing>
<crossing id="9" subroom1_id="1" subroom2_id="4">
    <vertex px="99.2" py="39.4"/>
    <vertex px="100.7" py="39.4"/>
</crossing>
<crossing id="10" subroom1_id="1" subroom2_id="4">
    <vertex px="111" py="39.4"/>
    <vertex px="109.5" py="39.4"/>
</crossing>
<crossing id="11" subroom1_id="2" subroom2_id="3">
    <vertex px="79.1" py="42.8"/>
    <vertex px="79.1" py="41.3"/>
</crossing>
<crossing id="12" subroom1_id="2" subroom2_id="3">
    <vertex px="79.1" py="31"/>
```

<vertex px="79.1" py="32.5"/>
</crossing>
<crossing id="13" subroom1_id="2" subroom2_id="5">
<vertex px="57.1" py="42.8"/>
<vertex px="57.1" py="41.3"/>
</crossing>
<crossing id="14" subroom1_id="2" subroom2_id="5">
<vertex px="57.1" py="31"/>
<vertex px="57.1" py="32.5"/>
</crossing>
<crossing id="15" subroom1_id="9" subroom2_id="10">
<vertex px="83.7" py="21.4"/>
<vertex px="83.7" py="19.9"/>
</crossing>
<crossing id="16" subroom1_id="9" subroom2_id="10">
<vertex px="83.7" py="9.6"/>
<vertex px="83.7" py="11.1"/>
</crossing>
<crossing id="17" subroom1_id="7" subroom2_id="10">
<vertex px="81.3" py="21.4"/>
<vertex px="81.3" py="19.9"/>
</crossing>
<crossing id="18" subroom1_id="7" subroom2_id="8">
<vertex px="59.3" py="21.4"/>
<vertex px="59.3" py="19.9"/>
</crossing>
<crossing id="19" subroom1_id="7" subroom2_id="10">
<vertex px="81.3" py="9.6"/>
<vertex px="81.3" py="11.1"/>
</crossing>
<crossing id="20" subroom1_id="7" subroom2_id="8">

```
                <vertex px="59.3" py="9.6"/>
                <vertex px="59.3" py="11.1"/>
            </crossing>
        </crossings>
    </room>
</rooms>
<transitions>
    <transition id="0" caption="exit" type="emergency" room1_id="0" subroom1_id="6" room2_id="-1" subroom2_id="-1">
        <vertex px="53.2" py="28"/>
        <vertex px="53.2" py="24.4"/>
    </transition>
    <transition id="1" caption="exit" type="emergency" room1_id="0" subroom1_id="6" room2_id="-1" subroom2_id="-1">
        <vertex px="104.7" py="30"/>
        <vertex px="104.7" py="22.4"/>
    </transition>
    <transition id="2" caption="exit" type="emergency" room1_id="0" subroom1_id="6" room2_id="-1" subroom2_id="-1">
        <vertex px="53.8" py="22.4"/>
        <vertex px="56.3" py="22.4"/>
    </transition>
    <transition id="3" caption="exit" type="emergency" room1_id="11" subroom1_id="11" room2_id="0" subroom2_id="6">
        <vertex px="98.2" py="22.4"/>
        <vertex px="101.7" py="22.4"/>
    </transition>

</transitions>
<Undefine/>
</geometry>
```

2. Input file for JPScore


```xml
        <?xml version="1.0" encoding="UTF-8" ?>

<JuPedSim project="JPS-Project" version="0.8"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">

  <!-- seed used for initialising random generator -->
  <seed>12542</seed>
  <max_sim_time>1800</max_sim_time>
  <num_threads>1</num_threads>
  <show_statistics>true</show_statistics>
  <logfile>log.txt</logfile>
  <!-- geometry file -->
  <geometry>plan4.xml</geometry>
  <!-- trajectories file and format -->
  <trajectories format="text" fps="8">
  <file location="plan4_traj.txt" />
  </trajectories>
  <!-- where to store the logs -->
  <!--<logfile>log.txt</logfile> -->


  <!-- traffic information: e.g closed doors -->
  <traffic_constraints>
     <door trans_id="0" caption="NaN" state="open"/>
        <door trans_id="1" caption="NaN" state="open"/>
        <door trans_id="2" caption="NaN" state="open"/>
  </traffic_constraints>

  <routing>
  </routing>
```

```xml
<!--persons information and distribution -->
<agents operational_model_id="3">
  <agents_distribution>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="0" number="40" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="1" number="10" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="2" number="15" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="3" number="15" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="4" number="15" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="5" number="20" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="6" number="15" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="7" number="10" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="8" number="15" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="9" number="25" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>
<group group_id="0" agent_parameter_id="1" room_id="0" subroom_id="10" number="30" goal_id="-1" router_id="1" pre_movement_mean="0" pre_movement_sigma="0"/>


  </agents_distribution>
</agents>
```

```
<!-- These parameters may be overwritten -->
<!-- These parameters may be overwritten -->
<operational_models>
  <model operational_model_id="1" description="gcfm">
    <model_parameters>
      <stepsize>0.01</stepsize>
      <exit_crossing_strategy>2</exit_crossing_strategy>
      <linkedcells enabled="true" cell_size="2.2" />
      <force_ped nu="0.3" dist_max="3" disteff_max="2" interpolation_width="0.1" />
      <force_wall nu="0.2" dist_max="3" disteff_max="2" interpolation_width="0.1" />
    </model_parameters>
    <agent_parameters agent_parameter_id="1">
      <v0 mu="1.19" sigma="0.0" />
      <bmax mu="0.25" sigma="0.001" />
      <bmin mu="0.20" sigma="0.001" />
      <amin mu="0.18" sigma="0.001" />
      <tau mu="0.5" sigma="0.001" />
      <atau mu="0.5" sigma="0.001" />
    </agent_parameters>
    <agent_parameters agent_parameter_id="2">
      <v0 mu="0.5" sigma="0.0" />
      <bmax mu="0.25" sigma="0.001" />
      <bmin mu="0.20" sigma="0.001" />
      <amin mu="0.18" sigma="0.001" />
      <tau mu="0.5" sigma="0.001" />
      <atau mu="0.5" sigma="0.001" />
    </agent_parameters>
  </model>

  <model operational_model_id="3" description="Tordeux2015">
    <model_parameters>
```

```
            <stepsize>0.05</stepsize>
            <exit_crossing_strategy>3</exit_crossing_strategy>
            <linkedcells enabled="true" cell_size="2" />
            <force_ped a="5" D="0.2"/>
            <force_wall a="5" D="0.02"/>
        </model_parameters>
        <agent_parameters agent_parameter_id="1">
            <v0 mu="1.19" sigma="0.0 " />
            <v0_upstairs mu="0.668" sigma="0.167" />
            <v0_downstairs mu="0.750" sigma="0.188" />
            <v0_idle_escalator_upstairs mu="0.5" sigma="0.0" />
            <v0_idle_escalator_downstairs mu="0.5" sigma="0.0" />
            <bmax mu="0.15" sigma="0.0" />
            <bmin mu="0.15" sigma="0.0" />
            <amin mu="0.15" sigma="0.0" />
            <tau mu="0.5" sigma="0.0" />
            <atau mu="0.0" sigma="0.0" />
            <T mu="1" sigma="0.0" />
        </agent_parameters>
    </model>
</operational_models>

<route_choice_models>
    <router router_id="1" description="ff_global_shortest">
           <parameters>

      </parameters>



    </router>
```

```
</route_choice_models>

</JuPedSim>
```


3. Input file for JPSreport


```
<?xml version="1.0" encoding="UTF-8"?>
<JPSreport project="corridor" version="0.8.5"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">

<geometry file="plan4.xml" />

<output location="plan4_output0" />

<trajectories format="txt" unit="m">

<file name="plan4_traj.txt" />

<path location="results" />

</trajectories>

<measurement_areas unit="m">

<area_B id="1" type="BoundingBox" zPos="None">

<vertex x="104.7" y="30" />

<vertex x="104.7" y="22.4" />

<vertex x="97.7" y="22.4" />

<vertex x="97.7" y="30" />
```

<length_in_movement_direction distance="4.0" />

</area_B>

<area_L id="2" type="Line" zPos="None">

<start x="101.7" y="30" />

<end x="104.7" y="30" />

</area_L>

</measurement_areas>

<velocity frame_step="10" set_movement_direction="None"
ignore_backward_movement="false" />

<method_A enabled="false">

<measurement_area id="2" frame_interval="10" />

</method_A>

<method_B enabled="false">

<measurement_area id="2" />

</method_B>

<method_C enabled="false">

```
<measurement_area id="1" plot_time_series="true" />

</method_C>

<method_D enabled="true">

<measurement_area id="1" start_frame="None" stop_frame="None"
        local_IFD="true"/>

<one_dimensional enabled="false"/>

<global_IFD enabled="true"/>

<cut_by_circle enabled="false" radius="1.0" edges="10"/>

<profiles enabled="true" grid_size_x="0.20" grid_size_y="0.20"/>

<output_voronoi_cells enabled="true" plot_graphs="true"/>

<use_blind_points enabled="true"/>

<vel_calculation type="Voronoi"/>

</method_D>

</JPSreport>
```

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