



UNIVERSIDADE DA BEIRA INTERIOR

Engenharia

# **Airport Evacuation Strategies for Passengers with Reduced Mobility: Simulation of Structural Configurations**

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Para a minha mãe



*“According to all known laws of aviation, there’s no way a bee should be able to fly. Its wings are too small to lift its fat little body of the ground. The bee, of course, flies anyway- because bees do not care about what humans think is impossible”*

*(From “Bee Movie”)*



## Dedicatory

Usually, in this topic a dedication is made to those who helped us while this work was done. However, I believe that I should dedicate this work to those who have served as inspiration to work with the highest quality possible. Thus, to all others a reference and a respective acknowledgment is made in the next topic.

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## Dedicatória

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## **Abstract**

Airport emergency cases are becoming more common; therefore, it becomes extremely important to have good emergency and evacuation protocols that are easily and quickly applied so the number of the affected is minimized. The simulation of these emergencies is important to implement evacuation plans and evaluate them. Evacuation plans are often idealized to passengers that in case of emergency are self-sufficient, able to physically attend themselves in their evacuation from the airport, not being optimized for passengers with reduced mobility that require assistance from others, and thus more time for evacuation. This study aims to understand and identify key issues about how passengers with reduced mobility are considered in current evacuation plans and also understand which possible solutions exist to optimize their evacuation. For that, it was performed an airport evacuation simulation using an egress simulation tool and obtained results that allow us to observe that when passengers with mobility impairments have egress routes and exits different from the other occupants, evacuation times decrease. Therefore, both groups of occupants may egress faster and through less congested doors.

## **Keywords**

Airport emergency; Emergency evacuation; Emergency accesses; Reduced mobility; Evacuation simulation tool; Airport evacuation; Evacuation strategies.



## Resumo

As situações de emergência em aeroportos são cada vez mais frequentes; sendo assim, torna-se extremamente importante ter bons planos de evacuação de fácil e rápida implementação de maneira a que o número de afetados seja mínimo. A simulação destas situações de emergência é importante para implementar e avaliar planos de evacuação. Estes planos são frequentemente idealizados para passageiros que, em caso de emergência são auto-suficientes, fisicamente capazes de abandonar o edifício sem ajuda de outros, não sendo otimizados para passageiros com mobilidade reduzida que requerem a assistência de outros e, portanto, mais tempo para a sua evacuação. Este estudo tem como objetivo compreender e identificar as principais questões no que diz respeito à forma como os passageiros com mobilidade reduzida são considerados nos planos de evacuação atuais e também entender que soluções possíveis existem para otimizar a sua evacuação. Para isso, foram realizadas simulações de evacuação de um terminal de aeroporto, utilizando uma ferramenta de simulação de evacuação e obtiveram-se resultados que permitem observar que, quando os passageiros com dificuldades de mobilidade têm rotas de evacuação e utilizam saídas diferentes dos outros ocupantes, os tempos de evacuação diminuem. Por conseguinte, ambos os grupos de ocupantes são evacuados mais rapidamente e por saídas menos congestionadas.

## Palavras-chave

Emergência num aeroporto; Evacuação de emergência; Acessos de emergência; Mobilidade reduzida; Ferramenta de simulação de evacuação; Evacuação de um aeroporto; Estratégias de evacuação.



# Table of Contents

Dedicatory.....	vii
Dedicatória.....	ix
Acknowledgments.....	xi
Abstract.....	xiii
Keywords .....	xiii
Resumo .....	xv
Palavras-chave .....	xv
Table of Contents.....	xvii
List of Tables .....	xxiii
List of Graphics.....	xxv
List of Acronyms .....	xxvii
Nomenclature .....	xxix
Chapter 1- Introduction.....	1
1.1    Motivation.....	1
1.2    Object and Objectives.....	4
1.3    Dissertation Structure .....	5
Chapter 2- Literature Review.....	7
2.1    Introduction .....	7
2.2    Building Evacuation .....	7
2.2.1    Factors that Influence the Evacuation of a Building .....	8
2.2.2    Standard Building Evacuation Systems.....	12
2.2.3    Evacuation Strategies.....	13
2.3    International and National Legal and Regulatory Framework .....	14
2.3.1    International Legislation .....	14
2.3.2    National Legislation .....	17
2.3.3    Evacuation Drills .....	22
2.4    Airport Emergencies .....	24
2.5    Passengers with Reduced Mobility.....	25
2.5.1    Rights and Duties .....	26
2.5.2    Infrastructural Obstacles.....	27
2.5.3    Emergency Situations .....	27
2.6    Accessibility Solutions .....	29
2.6.1    Evacuation Planning.....	29
2.6.2    Signage and Information Provided.....	30
2.6.3    Design Considerations.....	33
2.6.4    Evacuation Helpers/Devices for PRM.....	35
2.7    Emergency Evacuation Simulation Models .....	38
2.8    Conclusion .....	41

Chapter 3 - Evacuation Simulation Tool: <i>Pathfinder</i> .....	43
3.1 Introduction .....	43
3.2 Evacuation Simulation Tool: <i>Pathfinder</i> Basics and Definitions.....	43
3.2.1 Creating Movement Space .....	44
3.2.2 Creating Occupants .....	44
3.3 <i>Pathfinder</i> Validation Case .....	47
3.3.1 Characterization of Validation Case .....	48
3.3.2 Validation of the Simulation Features .....	50
3.3.2.1 First Validation Simulation: Drill n°1.....	52
3.3.2.2 Second Validation Simulation: Drill n°2 .....	53
3.3.3 Validation Results .....	54
3.4 Conclusion .....	59
Chapter 4 - Case Study .....	61
4.1 Introduction .....	61
4.2 Terminal A- Case Study Definition .....	61
4.3 Simulations in <i>Pathfinder</i> .....	64
4.3.1 Terminal A General Simulation Parameters .....	64
4.3.2 First Simulation-Original Geometry .....	72
4.3.3 Second Simulation.....	73
4.3.4 Third Simulation .....	77
4.3.5 Fourth Simulation .....	78
4.3.6 Fifth Simulation.....	78
4.3.7 Sixth Simulation .....	80
4.3.8 Seventh Simulation.....	81
4.4 <i>Pathfinder</i> Simulation Results.....	83
4.4.1 First Simulation .....	84
4.4.2 Second Simulation.....	87
4.4.3 Third Simulation .....	90
4.4.4 Fourth Simulation .....	93
4.4.5 Fifth Simulation.....	95
4.4.6 Sixth Simulation .....	97
4.4.7 Seventh Simulation.....	100
4.5 Conclusion .....	103
Chapter 5 - Discussion .....	105
5.1 Introduction .....	105
5.2 Analysis and Discussion of <i>Pathfinder</i> Simulation Results.....	105
5.3 Conclusion .....	109
Chapter 6 - Conclusions.....	111
6.1 Dissertation Synthesis .....	111
6.2 Final Considerations .....	112

6.3	Prospects for Future Work .....	114
	References .....	115
	Annexes.....	121
	Annex 1- Summary of Category Labels of Evacuation Egress Models .....	123
	Annex 2- <i>Pathfinder</i> 2015 and <i>Pathfinder</i> 2017 Main and Special Features .....	129
	Annex 3- Validation Case Specific Features.....	131
	Annex 4- Terminal A Floor Plans and 3D Views.....	139
	Annex 5- Terminal A and Simulation General Parameters .....	145
	Annex 6- Terminal A Specific Parameters for Each Simulation.....	147
	Annex 7- Compilation of Terminal A <i>Pathfinder</i> Simulation Results .....	153
	Annex 8- Views of Terminal A Simulation Geometries Generated (Navigation Meshes) ....	157
	Annex 9- Scientific Communications/Articles Accepted for Presentation/Publication .....	159



## List of Figures

Figure 1: Dissertation Methodological Approach .....	5
Figure 2: Factors that Influence the Evacuation of a Building.....	12
Figure 3: Major Flaws and Possible Solutions (Pires, Zorro & Silva, 2015b) .....	29
Figure 4: Narita International Airport Terminal 3 Signage (Thomas, 2015) .....	31
Figure 5: Narita International Airport Terminal 3 Signage Details (Thomas, 2015) .....	31
Figure 6: Dynamic Emergency Signage (Ferreira, 2016b) .....	32
Figure 7: Dynamic Emergency Signage for Exit Routes and Exit Doors (Ferreira, 2016) .....	33
Figure 8: Vancouver Airport Terminal Signage Example (Kazda & Caves, 2015) .....	35
Figure 9: Point of PRM Arrival at Airport (Kazda & Caves, 2015).....	35
Figure 10: <i>EVAC-CHAIR</i> Design (EVAC-CHAIR, 2015) .....	36
Figure 11: <i>EVAC-CHAIR</i> Glide Down Stairs and Rolls Across the Floor (EVAC-CHAIR, 2015) ....	36
Figure 12: Stair Slide (Altamash, 2015) .....	37
Figure 13: Differences of Evacuation Simulation Tools (Korhonen & Hostikka, 2010) .....	41
Figure 14: Occupant Editable Profile Parameters.....	45
Figure 15: Shoulder Width of Different PRM Types (in meter), (EMBRATUR, 2001).....	46
Figure 16: Occupant Editable Behavior Parameters .....	47
Figure 17: <i>Joalpe</i> (Joalpe, 2016).....	48
Figure 18: <i>Joalpe's</i> Plastic Unit (Ground and First Floor) and Wood Unit, respectively (Joalpe, 2016) .....	49
Figure 19: Validation Case Methodology .....	50
Figure 20: Validation Case Occupants' Profile Features .....	51
Figure 21: <i>Joalpe</i> Stairs' Features.....	51
Figure 22: <i>Joalpe</i> Stairs' Features (Risers) .....	52
Figure 23: <i>Joalpe</i> Exit Doors Location.....	52
Figure 24: <i>Joalpe</i> Drill n°1 Occupants' Behavior.....	53
Figure 25: <i>Joalpe</i> Drill n°2 Occupants' Behavior.....	54
Figure 26: Drill n°2 Pathfinder Geometry Mesh.....	54
Figure 27: Terminal A 3D Front Interior View (without Roof, Ceilings and Hidden First Floor) 62	
Figure 28: Terminal A 3D Back Interior View (without Roof, Ceilings and Hidden First Floor) 62	
Figure 29: Terminal A Ground Floor Plan (Divided by Room Type) .....	63
Figure 30: Terminal A First Floor Plan (Divided by Room Type) .....	63
Figure 31: Terminal A Occupants <i>Pathfinder</i> Label .....	69
Figure 32: Characteristics of Terminal A Occupants' Profiles .....	69
Figure 33: Terminal A Exit Doors Characteristics .....	70
Figure 34: Terminal A Interior Doors Characteristics.....	71
Figure 35: Terminal A Stair1 Characteristics.....	71
Figure 36: Terminal A Stair2 Characteristics.....	72
Figure 37: Terminal A Stair1 and Stair2 Characteristics .....	72

Figure 38: First Simulation (Sim 1 and Sim 1A) Occupants' Behavior .....	73
Figure 39: First Simulation (Sim 1 and Sim 1A) Geometry and Exit Doors Location .....	73
Figure 40: Second Simulation Occupants' Exit Choice Example .....	73
Figure 41: Terminal A Second Simulation Exit Groups (First Floor).....	74
Figure 42: Terminal A Second Simulation Exit Groups (Ground Floor) .....	75
Figure 43: Second Simulation Occupants' Behavior .....	76
Figure 44: Second Simulation Geometry and Exit Doors Location .....	76
Figure 45: PRM Emergency Door Characteristics .....	77
Figure 46: Third Simulation Occupants' Behavior.....	77
Figure 47: Third Simulation Geometry and Exit Doors Location.....	78
Figure 48: Separation Wall of PRM Emergency Door.....	78
Figure 49: Fifth Simulation Occupants' Behavior .....	79
Figure 50: Terminal A Fifth Simulation Ramps Location.....	79
Figure 51: Fifth Simulation Ramp Characteristics .....	80
Figure 52: Sixth Simulation Occupants' Behavior .....	81
Figure 53: Sixth Simulation Geometry and Refuge Areas Location .....	81
Figure 54: Seventh Simulation Occupants' Behavior .....	82
Figure 55: Seventh Simulation Geometry and Assistance Teams Location .....	83
Figure 56: Terminal A First Simulation Results (Inputs and Outputs) .....	84
Figure 57: Bad Configuration of Dining/Seating Areas and Unnecessary Walls of Terminal A .	85
Figure 58: Simulation 1 Occupants' Density at t=50,0 s .....	85
Figure 59: Simulation 1A Occupants' Density at t=50,0 s .....	85
Figure 60: Door Congestion in Simulations 1 and 1A .....	86
Figure 61: PRM Being Block by Other Occupants in Simulation 1 .....	86
Figure 62: Terminal A Simulation 2 Results (Inputs and Outputs).....	88
Figure 63: Simulation 2 occupants' Density at t=50,0 s.....	88
Figure 64: Some Configurational Alterations of Simulation 2 and its Impact in Density .....	89
Figure 65: PRM Occupants Being Blocked by Other Occupants in Simulation 2.....	89
Figure 66: Terminal A Simulation 3 Results (Inputs and Outputs).....	91
Figure 67: PRM Occupants Being Blocked in Simulation 3 .....	91
Figure 68: PRM Exiting through PRM Emergency Doors as Planned .....	91
Figure 69: Terminal A Simulation 4 Results (Inputs and Outputs).....	93
Figure 70: PRM Emergency Doors Correct Operation in Simulation 4 .....	93
Figure 71: Simulation 4 Last Exited Occupants.....	94
Figure 72: Terminal A Simulation 5 Results (Inputs and Outputs).....	96
Figure 73: Terminal A Simulation 6 Results (Inputs and Outputs).....	98
Figure 74: Example of a Refuge Area where Congestion does not Occur (Simulation 6).....	98
Figure 75: Example of a Refuge Area where Congestion Occurs (Simulation 6) .....	99
Figure 76: Terminal A Simulation 7 Results (Inputs and Outputs).....	101
Figure 77: Occupants being Assisted by Staff and Occupants Waiting for Assistance .....	101

## List of Tables

Table 1: Some Incidents Occurred in the XX Century and in the Beginning of the XXI Century (Averill et al, 2005; Seito et al., 2008) .....	1
Table 2: Pre-evacuation Times Defined in Literature (CFPA-Europe, 2009) .....	8
Table 3: Portuguese Emergency Safety Legislation in Buildings (Lourenço, 2013) .....	17
Table 4: Building Utilization-Types Definition (RJ-SCIE, 2008) .....	19
Table 5: Risk Places Division (RJ-SCIE, 2008) .....	20
Table 6: Fire Risk Categories Classification (RJ-SCIE, 2008) .....	20
Table 7: Fire Risk Categories Classification for Type XII Buildings (RJ-SCIE, 2008) .....	20
Table 8: Fire Risk Categories Classification for Type VIII Buildings (RJ-SCIE, 2008) .....	21
Table 9: Self-Protection Measures for Each Building Utilization-Type (RT-SCIE, 2008) .....	22
Table 10: Evacuation Drills Periodicity (RT-SCIE, 2008) .....	23
Table 11: Types of Evacuation Drills (ANCP, 2012) .....	24
Table 12: Average Walking Speeds for Horizontal Surfaces (CFPA-E, 2009).....	45
Table 13: Average Walking Speeds for Vertical Surfaces (CFPA-E, 2009).....	46
Table 14: <i>Joalpe</i> First Validation Results.....	55
Table 15: <i>Joalpe</i> Second Validation Results .....	56
Table 16: <i>Joalpe</i> Third Validation Results.....	56
Table 17: <i>Joalpe</i> Fourth Validation Simulation Results .....	57
Table 18: <i>Joalpe</i> Fifth Validation Simulation Results .....	58
Table 19: <i>Joalpe</i> Sixth Validation Simulation Results .....	58
Table 20: Calculation of the Maximum Number of Passengers (PRM Included) in Terminal A .	65
Table 21: Calculation of the Number of “Staff” Occupants in Terminal A .....	65
Table 22: Mobility Types Distribution (Percentage) ((US Department of Commerce, 1997) ...	66
Table 23: Calculation of Number of Occupants in Terminal A by Mobility Types .....	67
Table 24: Distribution of “ <i>Crutches</i> ”, “ <i>Hiker</i> ” and “ <i>Cane</i> ” Profiles in Terminal A.....	67
Table 25: Profiles Distribution in Terminal A .....	68
Table 26: Case of Study Simulation Results (Time of Evacuation) .....	83



## List of Graphics

Graphic 1: PWA Flow Rate in Simulation 1 .....	86
Graphic 2: BWA2 and FBS Flow Rate in Simulation 1 .....	87
Graphic 3: PWA Exit Doors Flow Rate in Simulation 2.....	89
Graphic 4: BWA Exit Doors Flow Rate in Simulation 2.....	90
Graphic 5: BWA2 and FBS Exit Door Flow Rate in Simulation 2.....	90
Graphic 6: PWA Exit Doors Flow Rate in Simulation 3.....	92
Graphic 7: BWA Exit Doors Flow Rate in Simulation 3.....	92
Graphic 8: BWA2 and FBS Exit Doors Flow Rate in Simulation 3.....	92
Graphic 9: PWA Exit Doors Flow Rate in Simulation 4.....	94
Graphic 10: BWA Exit Doors Flow Rate in Simulation 4 .....	95
Graphic 11: BWA2 and FBS Exit Doors Flow Rate in Simulation 4 .....	95
Graphic 12: PWA Exit Door Flow Rate in Simulation 5 .....	96
Graphic 13: BWA Exit Door Flow Rate in Simulation 5 .....	97
Graphic 14: BWA2 and FBS Exit Door Flow Rate in Simulation 5 .....	97
Graphic 15: PWA Exit Doors Flow Rate in Simulation 6 .....	99
Graphic 16: BWA Exit Doors Flow Rate in Simulation 6 .....	100
Graphic 17: BWA2 and FBS Exit Doors Flow Rate in Simulation 6 .....	100
Graphic 18: PWA Exit Doors Flow Rate in Simulation 7 .....	102
Graphic 19: BWA Exit Doors Flow Rate in Simulation 7 .....	102
Graphic 20: BWA2 and FBS Exit Doors Flow Rate in Simulation 7 .....	102



## List of Acronyms

2D	2 Dimensions
3D	3 Dimensions
ABCB	Australian Building Codes Board
ANAC	National (Portuguese) Authority of Civil Aviation
ANCP	National (Portuguese) Authority of Civil Protection
ANSI	American National Standards Institute
CAD	Computer Aided Design
CD	Compact Disk
CFPA-E	Confederation of Fire Protection Associations-Europe
DDA	Disability Discrimination Act
EC	European Commission
EU	European Union
GEEPs	General (or Group) Emergency Evacuation Plans
IBC	International Building Code
ICEUBI	International Conference on Engineering of University of Beira Interior
IED	Improvised Explosive Device
ISO	International Organization for Standardization
JFK	John Fitzgerald Kennedy International Airport
LAX	Los Angeles International Airport
LCC	Low Cost Carrier
MUTCD	Manual on Uniform Traffic Control Devices
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
OECD	Organization for Economic Co-operation and Development
PEEPs	Personal Emergency Evacuation Plans
PRM	Passengers with Reduced Mobility
RGEU	General Regulation of Urban Buildings
RJ-SCIE	Juridical Regulation for Fire Safety in Buildings
RSEU	Health Regulation in Urban Buildings
RT-SCIE	Technical Regulations for Fire Safety in Buildings
SCIE	Fire Safety in Buildings
SFPE	Society of Fire Protection Engineers
SO	Safety Officers
TRANSED	International Conference on Mobility and Transport for Elderly and Disabled Persons
UK	United Kingdom
UN	United Nations
US	United States

WHO

World Health Organization

## Nomenclature

AC	Always Closed
ACx	Air Career Number x
AO	Always Open
BWA	Boarding Waiting Area
BWA_FBSx	Door between BWA and FBS Number x
cm	Centimeter
Doorx	Interior Restrict or Non-restrict Door Number x
ED_dfree	Emergency Door of Duty-free Store1
ED_hall	Emergency Door of Hallway
ED_pc	Emergency Door of Post Card Store
ED_rac	Emergency Door of Rent-A-Car Store
ED_ramp	Emergency Door of Ramp1
EDrx	Emergency Door Number x
ED_sroom	Emergency Door of Staff Room
ED_storex	Emergency Door of Store Number x
EDx	Emergency Door Number x
Em. door	Emergency Door
FBS	Services of Foreign and Borders
Gate_AB	Door between Gate Number A and Gate Number B
Gatex	Gate Door Number x
m	Meter
m <sup>2</sup>	Square Meter
occ.	Occupants
occs/m <sup>2</sup>	Occupants per Square Meter (Density)
OF	Out of Format
Point 1	Gathering Point Number 1
Point 2	Point were an Injured is Located
PRM_EDx	Priority Emergency Door Number x
PU	Plastic Unit
PU_MainDoor	Plastic Unit Main Exit Door
PWA	Public Waiting Area
Ramp1	Ramp Number 1
Ramp1_x	Part Number x of Ramp1
Stairx	Stair Number x
Stairx_y	Part Number y of Stair Number x
t_drill	Time of the Drill Duration
t_drill_count	Time of Occupants Count in the Gathering Point

t_drill_recog	Time until Emergency Recognition by Occupants
t_evac	Time of Evacuation
t_first	Time of the First Occupant to Reach Point 1
t_injured_recog	Time of Recognition of Injured by Occupants
t_last	Time of the Last Occupant to Reach Point 1
t_last_door	Time of the Last Occupant to Exit through a Door
t_run	Time of Results Generation after the Geometry Computation
WCx	Door of WC Number x
WU	Wood Unit
WU_Main_Door	Wood Unit Main Exit Door

# Chapter 1- Introduction

## 1.1 Motivation

The study of human behavior in the evacuation of buildings has received increasing attention from the scientific community in recent decades. The complexity of some public buildings and the need to reconcile safety with a modern architecture and design, without neglecting the safety of its occupants, is one of the motivations for the interest of architects, engineers, but also mathematicians, physicists, scientists of computation, as well as sociologists in this matter.

In buildings with height or extension development (and sometimes both), where a high number of occupants with different levels of mobility coexist, safety concerns are a priority. The dramatic cases of recent history, caused by fires, earthquakes, terrorist attacks or riots, are well known. Table 1 show some of this incidents occurred in the XX century and in the beginning of the XXI century (Averill & Mileti, 2005; Seito et al., 2008).

Table 1: Some Incidents Occurred in the XX Century and in the Beginning of the XXI Century (Averill et al., 2005; Seito et al., 2008)

Year	Location	Incident	Casualties
1903	Iroquois Theatre, Chicago, USA	Fire More than 1600 people in the audience	600 Deaths
1908	Rhoads Opera, Lake View, USA	Fire (caused by a kerosene lamp)	170 Deaths
1908	Collinwood School, Lake View, USA	Fire	175 Deaths
1911	Triangle Shirtwaist, New York, USA	Fire Textile industry building with 10 floors	145 Deaths
1912	Equitable Building, New York, USA	Total Destruction 5 Buildings (the biggest had 10 floors)	7 Deaths
1945	Empire State Building, New York, USA	Airplane Crash (Airplane B-25) 78th and 79th floors	14 Deaths 25 Injured
1970	One New York Plaza, New York USA	Fire 33th and 34th floors (building with 50 floors)	4 Deaths 30 Injured
1972	Andraus Building, S.Paulo, Brazil	Fire Building with 31 floors Massive evacuation with helicopters	16 Deaths 336 Injured
1974	Joelma Building, S.Paulo, Brazil	Total Destruction Building with 23 floors	179 Deaths 320 Injured
1980	MGM Hotel, Las Vegas, USA	Fire Hotel with 21 floors	85 Deaths 770 Injured

Evacuation of 300 people with helicopters			
1988	Chiado, Lisbon, Portugal	Fire Stores in Carmo and Garret streets 18 buildings destroyed	2 Deaths >70 Injured
1989	Atlanta, Georgia, USA	Fire 18 buildings destroyed 1500 occupants	5 Deaths
1993	World Trade Center, New York, USA	Terrorist attack: explosion Parking floor Evacuation of 50.000 people in 8 hours Zone with 150.000 near buildings	6 Deaths 1.042 Injured
2001	World Trade Center, New York, USA	Airplane Crash: 2 planes Boeing 767 WTC1, floors 93 to 99 WTC2, floors 78 to 84 Estimated occupancy: 17.506	2.749 Deaths

Airports differ in complexity, but each has unique features. Some are small, uncomplicated facilities serving a more rural environment, while others represent a good-sized community with industrial and commercial installations serving major metropolitan areas. There are airports operated by local governments such as a city or county; or by an authority representing multiple local governments; and even some are operated by the State. However, one thing they all have in common is that they are all subject to emergencies.

In 2016 we saw the occurrence of two of the deadliest terrorist attacks within major international airports, indicating that airports have now become focal points for these types of attacks. The first one was the attack at Brussels Airport in Belgium, in march 2016 that resulted in 11 deaths and over 100 wounded as two bombs went off on either side of the airport's departures hall (BBC, 2016a).

The second attack was at Ataturk Airport in Istanbul, Turkey, in june 2016 that resulted in 41 deaths and more than 230 wounded as bombs went off in a car park, the first floor departures hall, and ground level arrivals hall (BBC, 2016b). Another bomb attack plotted against the Berlin Airport in Germany was foiled when a suspected was caught by German police (BBC, 2016c).

Since 2010 there have been at least 25 reported events that needed evacuation of at least one full airport terminal, which is a significant increase in reported evacuation events over previous decades. The majority of these events were caused by security concerns (including suspicious vehicles or luggage), security breaches and bomb threats (Ferreira, 2016).

Two separate events occurred in the United States (US) shortly after the bombings in Brussels and Istanbul, due to reports of sounds of shooting that later proved to be unfounded. The first

event occurred at John Fitzgerald Kennedy International Airport (JFK) in New York on August 14<sup>th</sup>, of 2016 (Paddock, 2016). The second event occurred at Los Angeles International Airport (LAX) in Los Angeles in September 2016 (Helsel, 2016).

For both the JFK and LAX incidents, reports of mass confusion, misinformation, chaos, and passenger panic accompanied the events. One particularly damning account of the JFK incident published in *New York Magazine* described police charging through terminals with guns drawn and passengers screaming (Wallace-Wells, 2016).

Also, in both the JFK and LAX incidents, passengers had been evacuated using tarmac exits without being directed to do so by airport personnel. In addition, airport staff were also reported to be unsure as to the nature of the event taking place and were unable to give accurate guidance to passengers on when and how to evacuate (Wallace-Wells, 2016).

These attacks and incidents reveal that airports are more commonly subjected to emergency evacuations and in a scenario like this, where thousands of people (that are not familiar with the building) are involved, the emergency evacuation plans must be extremely well thought and put in practice.

On the other hand, opportunities for air travel have grown significantly in recent years, with cheaper flights serving a wider range of destinations. For many people, this has made flying a more common experience. It is a matter of equity that disabled people and people/passengers with reduced mobility (PRM) should have opportunities for air travel comparable to those of other people. However, for people with a disability or mobility difficulty, the prospect of attempting a trip by air can seem fraught with potential difficulties. Thus, special consideration must be given to passengers and employees with restricted capabilities, as they may need assistance in the event of an emergency evacuation.

Panic and fear rule our mind in evacuation situations, everybody wants to move fast and get to a safe place; as such, people with disabilities that cannot move faster will be easily left behind and if in normal days they are left hours waiting for assistance, in a situation of evacuation they wouldn't even be remembered by staff.

Common experience reveals that persons with disabilities are more likely to be left behind or abandoned during evacuation in disasters and conflicts due to a lack of preparation and planning, as well as inaccessible facilities and services and transportation systems.

As referred above, since airports receive millions of people a year they end up becoming infrastructures vulnerable to terrorist attacks or incidents that may trigger an emergency evacuation and that is why training, drills and evacuation plans should be rethought and consider disabled people necessities and airports must adopt strategies that allow those people to at least try to self-evacuate or be evacuated fastest. However, this type of building can't easily or often execute drills involving the closure of its services or the involvement of passengers due to the financial loss that would result from it.

Safety is a crucial concept in aviation industry and it will always need improvements because unpredictable human and nature factors will always exist. The use of technologies that simulate virtually emergency evacuations end up solving this problem in a practical, economical, valid and safe way. These tools also have the advantage of making possible to evaluate the accessibility level of any type of building.

To improve safety for everyone this dissertation intends to understand which factors influence a building evacuation, and also answer to some of the dependent populations needs in emergency evacuation scenarios.

## **1.2 Object and Objectives**

The object of this dissertation is the infrastructure emergency evacuations, the factors that influence the evacuation in a building, the evacuation procedures of dependent populations and major evacuation constraints of passengers with reduced mobility and the evacuation simulation tools used to analyze infrastructures.

The main objective of this study is divided in two sub-objectives: the validation of a specific evacuation simulation tool through the analyses of an industrial building with real data and the implementation of this tool in the analyses of an imaginary airport with similar characteristics of Portuguese airports.

Unfortunately, with the inability to access actual data from airports (evacuation procedures, training and drills data and building plans) and with the need to validate the simulation software drill reports and evacuation plans were requested to a company referenced as an example of excellence regarding compliance with safety standards. Thus, the first sub-objective is to analyze the provided data with a simulation tool and compare them with the results obtained to validate, or not, this software.

In case of confirming the software validation in the first sub-objective we can proceed to analyze the same type of data to an airport building (case study). Thus, the second sub-objective of this work is to create and study/analyze several evacuation scenarios in an airport infrastructure with a simulation tool aiming to better understand the occupants' behavior. In this sub-objective, the occupants are divided in three groups: airport staff, passengers, and passengers with reduced mobility (with different types of mobility impairments).

The flowchart of Figure 1 represents the methodology applied in this dissertation.

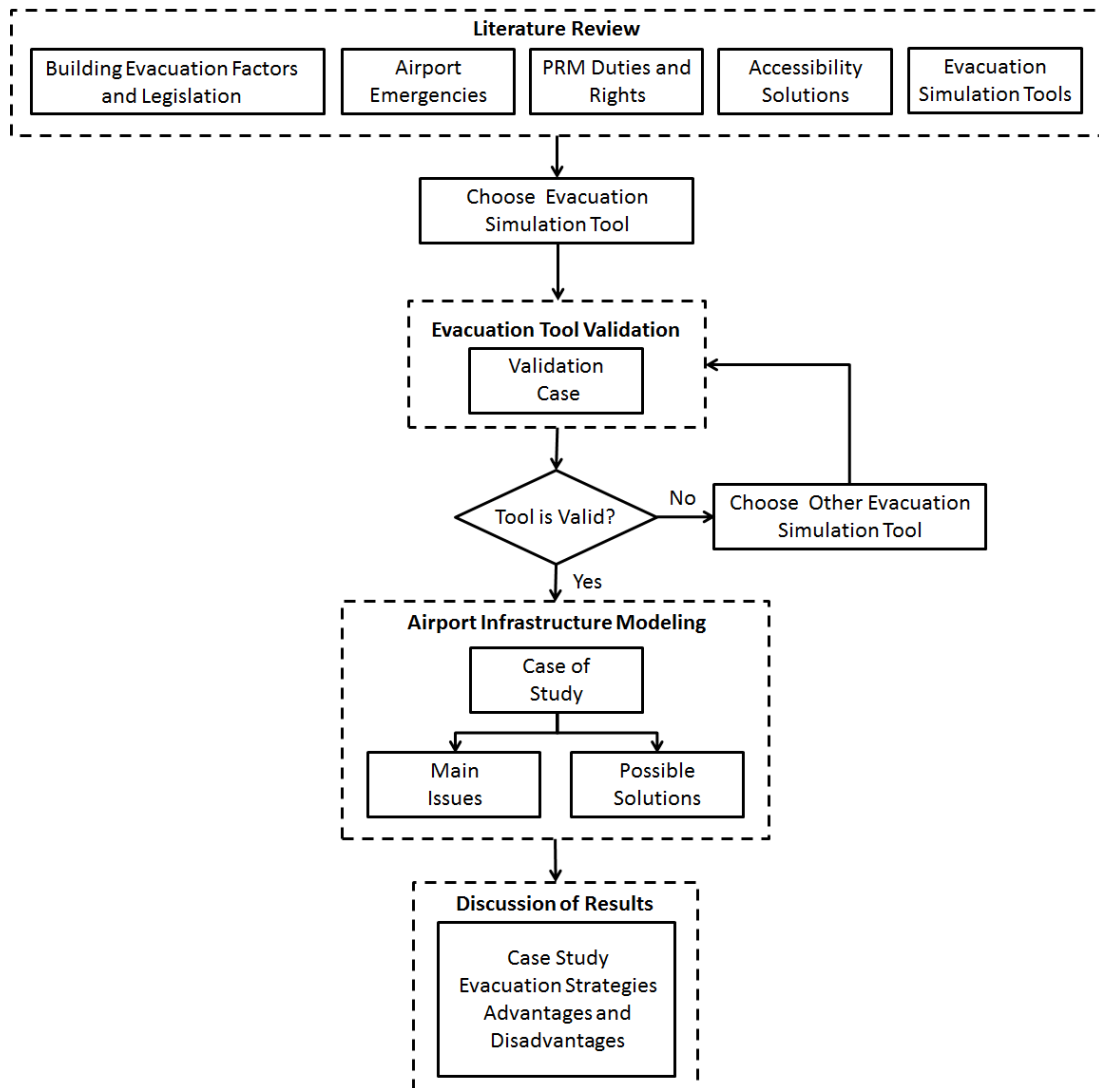


Figure 1: Dissertation Methodological Approach

### 1.3 Dissertation Structure

This dissertation development started with a literature review of the airport emergencies, evacuation procedures and dependent populations major impairments. Then, a large research on evacuation simulation tools was conducted to understand which tool was recommended to this type of analysis. The first chapter is the study introduction, which is divided into three sub-chapters, the motivation, the object and objective, and the structure of the dissertation, respectively.

The second chapter corresponds to the state of the art and contains the studied themes of airport emergencies, building evacuation and the international and national legislation inherent to this subject, evacuation strategies, evacuation drills, dependent population and possible solutions to decrease dependent population's movement impairments and the evacuation simulation tools and its features.

The third chapter is entirely dedicated to the basics of *Pathfinder*, the simulation tool used in this study, and to the first sub-objective of this work. Accordingly, the tool validation it is made by testing real data from executed drills (provided by a company with high standards of safety) with *Pathfinder*.

In the fourth chapter a case of study is defined and analyzed in *Pathfinder* and all the simulation parameters and results are presented.

The fifth chapter addresses the discussion of simulation results.

The sixth (and last) chapter contemplates the dissertation synthesis, the final considerations, and the prospects for future work regarding this matter.

# Chapter 2- Literature Review

## 2.1 Introduction

This chapter describes the state of the art review concerning airport emergencies and its response, factors that influence buildings' evacuation and the importance of training drills and evacuation plans. It also includes information about evacuation strategies and some regulation about infrastructures safety measures and procedures.

The dependent populations, their rights and duties, their evacuation in emergency situations and the concept of passenger with reduced mobility are also developed and some existing solutions (infrastructural/physical and others) that improve the evacuation (or self-evacuation) of the dependent populations from buildings are presented.

Egress evacuation simulation models and their features are also referred, and some of which are classified according to international entities expert in the subject.

## 2.2 Building Evacuation

The emergency evacuation is the process in which occupants in a building (O'Connor, 2005):

- Face off a threat or a disastrous event;
- Experience several mental processes and trigger various actions before and/or during the movement to a safe place, which can be within or outside a building.

This process is characterized by three basic activities (Kobes, 2010; O'Connor, 2005):

- **Warning of danger by an external stimulus:** validation period;
- **Validation and response to risk indicators:** decision-making period;
- **Drive to a safe place:** movement period.

The first two periods, validation and decision making, are called pre-movement phase.

Pre-evacuation phase is the time spent since the occupant receives the external stimulus to start the escape route. During this stage, a person can perform other activities that do not aim to abandon the structure in emergency (Bryan, 1992).

This phase takes extremely importance in the evacuation because there is a direct link between these delays and a high number of fatalities. The process at this stage may be more crucial than the movement speed (Bryan, 1992).

There are pre-evacuation times defined in literature, studied in the analysis of previous executed evacuation drills. In Table 2, are indicated the expected times for different types of building according to the familiarity with the building, the probability of occupants being awake and the occupants' dependency level. These times also differ per alarm system and the occupants' training level (CFPA-Europe, 2009).

Table 2: Pre-evacuation Times Defined in Literature (CFPA-Europe, 2009)

Type of Building	W1 [min]	W2 [min]	W3 [min]
Offices, commercial and industrial buildings/factories, schools, and universities (occupants awake and familiar with the building, with the alarm system and with the evacuation procedures)	<1	3	>4
Malls, museums, gyms, airport terminals and other buildings frequented by several people (occupants awake but not familiar with the building, with the alarm system and with the evacuation procedures)	<2	3	>6
Dormitories, high and medium residential buildings (occupants may be asleep but are familiar with the building, alarm system and evacuation procedures)	<2	4	>5
Hotels and inns (occupants may be asleep but are relatively familiar with the building, alarm system and evacuation procedures)	<2	4	>6
Hospitals, maternities, and other institutional buildings (a significantly high number of occupants may need assistance in the evacuation)	<3	5	>8

Where the times W1, W2 and W3 correspond to times in scenarios with different alarm systems (CFPA-Europe, 2009):

- **W1:** voice communication alert systems from a control room or direct instructions (visible and audible in the all building) with staff well trained for emergencies;
- **W2:** voice messages pre-recorded and/or visual alarm systems with staff well trained for emergencies;
- **W3:** audio alarm systems without staff trained for emergencies.

However, there are more factors that influence the time that a person takes to leave a building in an emergency.

### 2.2.1 Factors that Influence the Evacuation of a Building

A building is, normally, evacuated due to an emergency. Thus, it is not only important to understand which infrastructural factors influence the movement and the occupants flow but is also important to understand how people react in this type of situation. According to the literature, the individual response performance to an emergency is the human capacity to perceive and interpret danger signals, make decisions and put those decisions into practice so that survival is assured (Kobes, Helslot, Vries, & Post, 2010).

In other literature reference, it is also suggested that the individual response performance to an emergency may change during the escape and depends on the surrounding conditions. This means that the performance does not depend only on personal characteristics but also on the environment, such as the characteristics of the building and the emergency itself (a fire, an earthquake, for example) (Sime, 2001).

### **Building Characteristics**

A building's architectural and infrastructural features (height, width, enclosures, etc.) and the way people interact with it have a direct impact on the response to an emergency. A simpler or more complex shape, rooms, exits and signs may affect the response of occupants (Gwynne, Galea, Lawrence, & Filippidis, 2001).

The occupancy of the building it is also an important factor. The occupant load of a room is the maximum number of persons anticipated to be present for a given configuration or use. Therefore, designers should have in mind that the numbers and distribution of occupants in a building will affect the evacuation time and procedures (CFPA-E, 2009).

In case of emergency the ease in finding the way of escape is very important for survival. The choice of the escape route is determined by the spatial knowledge level, the level of architectural differentiation, the presence of evacuation signs, among other factors. Recently published studies demonstrated that the occupant rarely sense the presence of emergency sign paths located on the roof or at least the exit choice is not based on it (Kobes, Helslot, Vries, & Post, 2010).

If the sign is on a lower level, near the ground, it has a positive influence on choice of evacuation route. However, if it is in the ceiling, smoke (when it exists) may difficult its visualization (Kobes et al., 2010).

People often use the routes that lead to known exits and rarely leave by the emergency exits. The user choice of an exit is not just based on proximity or signing, it can be influenced by social norms of occupants involved. The emergency exits are not used day-by-day and neither will in emergency situations: they will only be used if they are opened and the distance to the main entrance is more than twice the distance to the emergency exit (Kobes, Helslot, Vries, & Post, 2010; Paulsen, 1984).

### **Human Characteristics: Behavior and Individual Factors**

Over the last decades, human behavior has been recognized as a crucial factor in the loss of lives during emergencies, since some occupants aim to look first for family or friends, for valuables or even to try to extinguish a fire, and only then aim to exit the building (Coelho, 1997; Wolshon, 2016).

The human characteristics that can also influence the behavior and the choices adopted by occupants in emergency situations are:

- **Gender:** men and women have different behaviors regarding the reaction to an emergency. While in the case of men are more likely to seek the origin of the emergency and try to extinguish it, women warn other occupants, seek their family, call for help and leave the building (Bryan, 1992; Coelho, 1997);
- **Age:** old and young people recognize alarms with more difficulty but once young people have decided to move, they are quick and strong to face smoke and heat, for

example. These group of occupants also have difficulties in evacuating without assistance (CFPA-Europe, 2009; Proulx, 2003);

- **Physical impairments and mental ability:** the initial response of a disabled person may involve a considerable preparation time before moving and might need assistance to evacuate. Their movement is significantly influenced by the nature of their disability and building elements such as doors, ramps and stairs (CFPA-Europe, 2009);
- **Personality:** if the person is a natural leader or a follower, the stress level of resistance and the self-assurance can influence the response to an emergency (Kobes, Helslot, Vries, & Post, 2010);
- **Medication, drugs and alcohol:** the presence of these substances in human blood flow can reduce the level of attention and the ability to recognize a dangerous situation, influencing the reaction to a threat (Proulx, 2003; Silva, 2007).

### Human Characteristics: Social Factors

In addition to the physical and individual factors, there are also social factors that can affect the response to an emergency. Social influence is extremely important in the decision-making process in the pre-evacuation stage (Nilsson & Johansson, 2009).

Some of these social factors are:

- **The behavior of other people:** the action or inaction of the people around an individual may influence the perception of this individual and his behavior. If someone starts moving towards an exit, everyone is likely to follow, but the opposite is also true, inactivity of the elements of the group can inhibit the actions of those involved. Also, people's inertia can convey the message that the danger is not real, inhibiting the response. If the threat is ambiguous, the individual analyses the behavior of the people around him to obtain more information about the situation (Nilsson & Johansson, 2009);
- **Activities of the occupants before the emergency:** the commitment dedicated by some occupants to certain tasks may delay the beginning of their escape because they tend to finish the task first and only then they decide to leave the building (Kobes, Helslot, Vries, & Post, 2010; Meacham & Custer, 1999; Proulx, 2003, 2007);
- **Family or group relationships:** response to alarms or fire cues is affected by whether people are alone or with others and the presence of other people can have an inhibiting effect on the initiation of the response to the emergency because in these cases people are likely to attempt to reestablish the group unlike people who are alone that tend to respond more quickly. It is also important to remind that the speed of movement of a group will often be dictated by the slowest elements of the group (CFPA-E, 2009);

- **Role and responsibility:** the rules and the responsibilities of occupants during the normal use of the building will influence their behavior and the behavior of others. Therefore, sufficient, well trained and authoritarian/commanding staff will shorten the ambiguous, information-gathering phase of pre-movement time (Kobes, Helslot, Vries, & Post, 2010; Shields & Boyce, 2000).

#### Human Characteristics: Situational Factors

There are also some factors that influence an evacuation related to the moment in which the incident begins that only at that moment can be known or analyzed. Some of these factors are (CFPA-E, 2009):

- **Alertness:** depend on factors such as activities, time of the day and if the occupants are asleep or awake;
- **Distribution of occupants in the building:** the exact position of an occupant when an incident occurs will affect several decisions and consequently influence his egress process;
- **Familiarity of the occupants with the building:** the presence of visitors (for example) normally assumes a passive attitude and this will influence the behavior of the usual occupants of the building.

#### Emergency/Threat Characteristics

Obviously, the characteristics of the actual threat will always influence the behavior of the building's occupants and sometimes influence the physical characteristics of the building.

Explosions and earthquakes, for example, can destroy some infrastructures or parts of the building and block exits and the access of the usual egress paths.

Exposure to fire can have several negative effects on human response, due to high temperature and smoke exposure. The effects of temperature on the body of a human being may vary according to the time of exposure, the amount of relative humidity and the characteristics of the clothing used (Meacham & Custer, 1999).

Smoke is also a strong indicator that something is wrong and that it is necessary to escape as quickly as possible. The presence of smoke does not stop the movement of the occupants, even in the worst conditions, it stimulates the occupants' reaction (Gwynne et al., 2001; Kobes, Helslot, Vries, & Post, 2010; Meacham & Custer, 1999). It is important to notice that, when there is continuous inhalation of smoke, occupants tend to move slower (Gwynne et al., 2001).

Some people are willing to go through the smoke and only redefine the escape route or go back when they can't see or when they have problems in breathing, sense fear or for other reasons. When visibility is reduced, people also tend to walk against the walls (Coelho, 1997; Kobes, Helslot, Vries, & Post, 2010; Proulx, 2003).

In some cases, the combustion of specific materials can release gases with negative effects on people like loss of conscience or even death (Kobes, Helslot, Vries, & Post, 2010).

Thus, according to all the information above we can conclude that the factors that influence the evacuation of a building are the following, summarized in Figure 2.

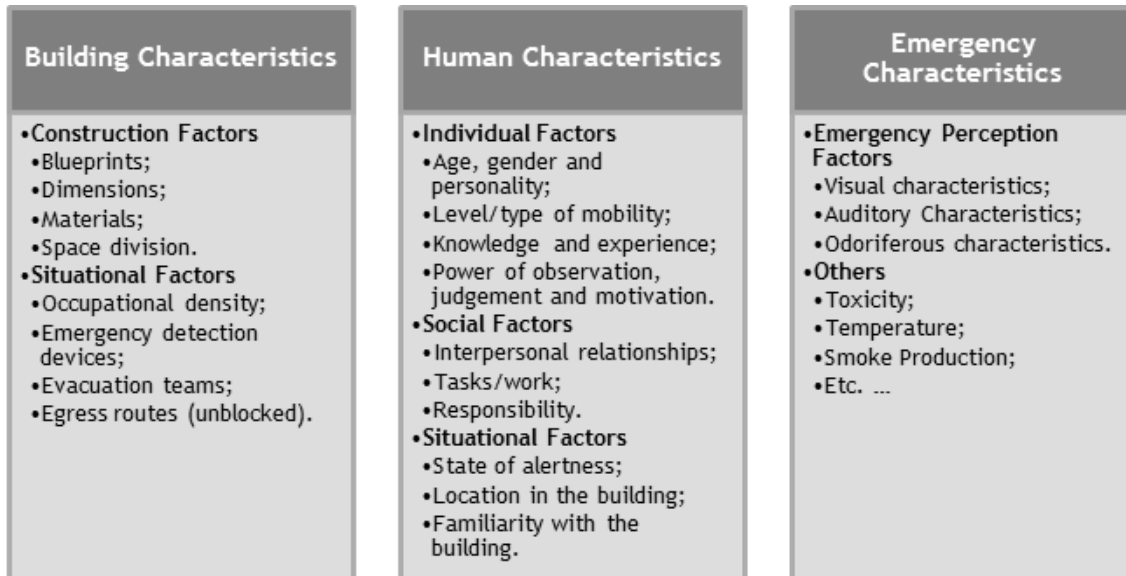


Figure 2: Factors that Influence the Evacuation of a Building

### 2.2.2 Standard Building Evacuation Systems

A standard building evacuation system has three components: the circulation path, the occupant notification system(s) and the directions to and through the circulation paths (NFPA, 2016).

A circulation path or an evacuation/egress route is a continuous and unobstructed way of travel from any point in a building/structure to a public way (exterior to the building). The components of a circulation path include (but are not limited to) rooms, corridors, doors, stairs, smoke-proof enclosures, horizontal exits, ramps, exit passageways, escalators, moving walkways, fire escape stairs, fire escape ladders, slide escapes, alternating tread devices, refuge areas, and elevators and it is considered a usable circulation path if it meets one of the following criteria (NFPA, 2016):

- A person with disabilities can travel unassisted through the circulation path to a public way;
- A person with disabilities can travel unassisted through that portion of the circulation path necessary to reach an area of refuge (that serves as a temporary haven from the effects of a fire or other emergency).

If elevation differences exist, an elevator or other evacuation device might be used, or the person might be moved by other people using a cradle carry, a swing (seat) carry, or an in-chair carry or by a stair descent device (NFPA, 2016).

The occupant notification systems include but are not limited to alarms and public address systems. The National Fire Protection Association (NFPA) Code 72, the National Fire Alarm Code, defines a notification appliance as “a fire alarm system component such as a bell, horn, speaker, light, or text display that provides audible, tactile, or visible outputs, or any combination thereof”, (NFPA, 2007:21).

Directions to and through the usable circulation path includes signage, oral instructions, and other instructions, which may be live or automated, broadcast over a public address system (NFPA, 2016).

Personal notification devices, which have recently come onto the market, can be activated in several ways, including but not limited to having a building’s alarm system relay information to the device. Although, because this technology is new to the market, such devices and systems are not discussed yet in national or international codes; however, emergency evacuation personnel and people with disabilities may (and should) want to investigate them further (NFPA, 2016).

### 2.2.3 Evacuation Strategies

It is natural that those responsible in legal terms for safety in buildings, given the applicable legislation and the current fire safety conditions of their establishments, ask themselves about the best emergency evacuation strategy they can apply, minimizing the investment necessary to its implementation (a factor certainly relevant because of the current financial crisis) without jeopardizing its efficiency and effectiveness. Obviously, better than having a good response plan to emergency, is to have a good and efficient prevention plan (Medeiros, 2012).

In this circumstance, the key question is: what is the best evacuation strategy? To answer this question, one of the fundamental criteria is to know the degree of dependence of the building’s occupants in terms of mobility, perception and reaction to an alarm. The degree of occupants’ dependency can be subdivided into three categories (Medeiros, 2012):

- **Independent:** occupants physically able to leave the building without help from staff or from another person, in case of emergency;
- **Very dependent:** occupants whose physical condition implies the difficulty to move without being dependent on the help of other people;
- **Dependent:** all occupants that are not included in the previous categories (total dependency).

Having in consideration the degree of dependency of the occupants and their location on the building, it is natural that the evacuation strategy most appropriate, to the standard use of each building, is not uniform throughout the facility but instead consists of a combination of several evacuation strategies such as (Medeiros, 2012):

- **Simple evacuation:** more appropriate in those places/services in which the occupants predominantly belong to the category of the independents;
- **Progressive horizontal evacuation:** necessary where the occupants are dependent on help to evacuate. It consists on the movement of occupants from the location affected by the threat to an adjacent sub-area or fire-fighting compartment located on the same floor where occupants can wait in safety while the threat is controlled or to wait for a subsequent evacuation to another similar fire compartment where, if necessary, an evacuation is carried out through a protected vertical escape route to a totally safe location;
- **Deferred evacuation:** in some places of the building it may not be desirable or practical to evacuate the occupants immediately. In these circumstances, it may be appropriate to allow occupants to remain where they are while the threat is being fight, or to gain additional time needed to prepare for their evacuation; this strategy applies for example to hospital surgery rooms. For this strategy to be implemented, these places must be fire-rated. However, even where this strategy is adopted, an evacuation plan appropriate to the reality of the location and the specificity of their occupants is required.

In accordance to the statements above, internal emergency plans should have the necessary flexibility to incorporate the most appropriate strategies to the specific characteristics of their human occupation, being normal the inclusion of different evacuation strategies for the same evacuation plan (Medeiros, 2012).

## 2.3 International and National Legal and Regulatory Framework

### 2.3.1 International Legislation

When we consider fire/emergency safety codes, ordinances, standards, and similar legislation, we must consider that different legislation exists in nearly every nation. In some nations, these documents are extensive and complete while in others are extremely basic, if not primitive and the origins of nearly all of this legislation are as varied as the number of countries where it is applied.

In the US, over the past 100 years, the federal government has enacted substantial legislation on fire safety and fire prevention. However, each state, county, and municipality creates and applies legislation tailored to its particular wants and needs, often conflicting with the needs of a neighboring community (Potter, 2008).

The US standards and codes are mainly created in the American National Standards Institute (ANSI), which coordinates the creation and diffusion of codes and standards related to nearly every activity in the country (including fire safety). Many ANSI standards are referenced in building codes like the International Building Code (IBC). The main source of fire/emergency

safety standards in US is the NFPA, which publishes and constantly updates most codes that form the basis for national, state, and local legislation. Although the NFPA standards and codes are not legislation but rather documents of recommended good practice, they form the foundation on which nearly all US fire safety legislation is based (Potter, 2008).

Some other entities (that exist in the US) also contribute to the creation of fire/emergency safety legislation, either through documents or by serving as approval bodies for materials, equipment, systems, and so forth. These include the National Institute of Standards and Technology (NIST), the federal technology agency that develops and promotes standards, measurements, and technology, the American Society for Testing and Materials, the Underwriters Laboratories, Inc., the Factory Mutual and the National Fire Sprinkler Association, among many others (Potter, 2008).

Internationally, there are as many legislative bodies as there are countries. The 50 independent countries comprising Europe have each developed specific regulations for their own territories and the 28 countries of the European Union (EU) have consolidated much of their individual legislation and codes, often sacrificing particular national interests to an effort toward standardization, for example, making a particular standard on portable fire extinguisher classifications or fire detection system and component specifications commonly applicable throughout all the members/countries (Potter, 2008).

In these countries, contrary to what happens in US, the standards and codes apply to the entire nation. On this international level, the International Standards Organization (ISO) is the worldwide standards-producing body comprising the national entities of 157 countries, providing information, products, and services related to property and liability risks. The ISO standards meet and often exceed individual national ones and have profound influence on national legislation and standards around the world (Potter, 2008).

Over the last decades, several initiatives intended to improve fire/emergency safety in Europe have emerged from diverse forums. In the beginning, most of these efforts did not get much further than proposals. However, during the more recent years of this century, several of these initiatives have received support from the European Commission (EC), (Potter, 2008).

In Central and South America, a most of the 43 nations, republics, island states, and protectorates have based their fire/emergency protection legislation and standards on those of the US, specifically those provided by NFPA. Some others have created their own legislation based on their particular characteristics, and still others have looked to Europe for guidelines. Some countries such as Mexico and Peru have extensive national and regional regulations, whereas a few countries make direct reference to specific NFPA codes (Potter, 2008).

Australia and New Zealand have extensive legislation covering building design and construction as well as standards for equipment, systems, and installations. Australia also has a very high ratio of research and testing facilities in relation to its population, performing

some of the world's most advanced investigation and research projects in fire/emergency protection (Potter, 2008).

In Asia, Japan is probably the leader in safety regulations for buildings, in part because of the particular characteristics of the nation's high number of residential infrastructures and small-to medium-business facilities. The Philippines and China have recently made huge developments in improving regulations on building characteristics and safety, mostly related to the latest fires that caused many fatalities. However, these two countries still have limited fire suppression capabilities (Potter, 2008).

In Africa, the Republic of South Africa has numerous fire/emergency prevention and protection codes in effect, followed by certain other countries in North Africa (Algeria, Egypt, Tunisia, and Morocco) although these are far behind South Africa regarding extensive or exacting legislation. In other countries, fire/emergency prevention and protection is given little or no consideration (Potter, 2008).

As can be seen, much has been done in many regions and countries with the objective of reducing life and property losses due to fire/emergencies, but in other areas there is still much yet to be done. Historically, the US has probably been the world leader in fire prevention and protection. Although the US may be a leader in fire/emergency protection systems, it does not come close to many European countries and Japan in fire/emergency prevention (Potter, 2008).

After an exhaustive research on international laws, codes and standards, it is concluded that there is some international standards that can be take in account as a quality references. These standards are:

- **ISO 15928-4/2008:** sets out a method for describing the fire safety performance of houses. To sum up, this standard covers user needs, provides performance descriptions, and outlines evaluation processes, includes the description of relevant parameters for early warning, fire suppression, fire containment and means of egress (ISO 15928, 2008);
- **ISO 22315/2014:** provides guidelines for mass evacuation planning in terms of establishing, implementing, monitoring, evaluating, reviewing and improving preparedness. It also establishes a framework for each activity in mass evacuation planning for all identified hazards. Thus, it helps organizations to develop plans that are evidence-based and that can be evaluated for their effectiveness (ISO 22315, 2014);
- **ISO 22320/2011:** establishes requirements for operational information for incident response which specifies processes, systems of work, data capture and management to produce timely, relevant and accurate information (ISO 22320, 2011).

### 2.3.2 National Legislation

The Urban Building Salubrity Regulation (RSEU), published by Decreto-Lei of february 14<sup>th</sup>, in 1903, was a pioneer in Portugal by establishing the hygienic conditions to be adopted in the construction of buildings, and also approached, superficially, accessibility issues and other important requirements for fire safety (Lourenço, 2013).

The General Regulation on Urban Buildings (RGEU), approved by Decreto-Lei n°38382 of august 7<sup>th</sup>, in 1951, was one of the first regulations to address fire safety in buildings, although in a very general and not very thorough way, imposing some safety conditions and the restriction on the use of some combustible materials (Lourenço, 2013).

The publication of several legislation diplomas on fire safety in buildings was followed but, in general, each one addressed a specific area/type of building, with some buildings being not addressed in these same diplomas. To the buildings that until then were outside the specific scope of regulations, the legal framework was made by the RGEU, leaving a legal void and a need to regulate the conditions of fire safety, as can be seen in Table 3 (Lourenço, 2013).

The lack of comprehensiveness in the regulation and application of the minimum legal conditions required for the existing and in construction building, has fostered the appearance of the current Juridical Regulation for Building Fire Safety (RJ-SCIE), approved by Decreto-Lei n°220/2008 of november 12<sup>th</sup> (Lourenço, 2013).

Therefore, the legislation applicable to compliance with the minimum fire safety requirements in buildings starts being established in Portugal by RJ-SCIE, together with the Technical Regulation on Fire Safety, RT-SCIE (Portaria 1532/2008 of december 29<sup>th</sup>), (Lourenço, 2013).

Table 3: Portuguese Emergency Safety Legislation in Buildings (Lourenço, 2013)

Building Usage	Before 2009	After 2009
Habitational Buildings	Decreto-Lei n°64/90 of february 21 <sup>st</sup>	Decreto-Lei n°220/2008 of November 12 <sup>th</sup> (RJ-SCIE)  Technical Regulation for Building Fire Safety, RT-SCIE  (Portaria 1532/2008 of december 29 <sup>th</sup> )
Parking Lots	Decreto-Lei n°66/95 of april 9 <sup>th</sup>	
Administrative Buildings	Decreto-Lei n°410/98 of december 31 <sup>st</sup>	
Educational Buildings	Decreto-Lei n°414/95 of december 31 <sup>st</sup>	
Hospital Buildings	Decreto-Lei n°409/98 of december 23 <sup>rd</sup>	
Tourist Real Estate Developments	Portaria 1063/97 of october 21 <sup>st</sup>	
Nursing Homes, Hotel, Catering, Sports and Leisure Buildings, Museums and Art	RGEU	

Galleries, Libraries and Archives	
Entertainment Buildings	Decreto-Lei nº34/95 of december
Commercial and Transports Platforms and Terminals Buildings	Decreto-Lei nº68/99 of september 18 <sup>th</sup>
Industrial, Manufactory Buildings and Warehouses	RGEU

In Portugal, it is the responsibility of the National Civil Protection Authority (ANPC) to ensure the safety and maintenance conditions of the buildings in its conception, making them safer, from the design phase to the execution of the construction works and throughout their useful life. In the prevention of natural and technological risks scope, among other competences, it includes the regulation and inspection of the fire safety conditions in buildings and enclosures (RJ-SCIE, 2008).

The RJ-SCIE has come to compile an excess of scattered legislative documents. The diplomas compiled in this regulation are the following (ANPC, 2012):

- **Portaria nº64/2009 of january 22<sup>nd</sup>**: establishes the system of accreditation of entities by ANPC to issue opinions, conduct audits and inspections of fire safety in buildings (SCIE);
- **Portaria nº610/2009 of june 8<sup>th</sup>**: regulates the operation of the computer system provided in nº2 of article 32<sup>nd</sup> of the Decreto-Lei nº220/2008, of November 12<sup>th</sup> (registration of the activity of marketing, installation, maintenance of SCIE equipment);
- **Portaria nº773/2009 of july 21<sup>st</sup>**: defines the procedure for registering, at ANPC, entities that carry out the commercialization, installation and/or maintenance of SCIE products and equipment;
- **Portaria nº1054/2009 of september 16<sup>th</sup>**: defines the fees for fire safety services in buildings provided by ANPC.

There is, in addition:

- **Order nº2074/2009 of the ANPC president**: technical criteria for determination of modified fire load density (ANCP, 2012);
- **Decreto-Lei nº163/6 of august 8<sup>th</sup>**: defines the accessibility conditions for disabled people, that is, people in wheelchairs, people who are unable to walk or who can't travel long distances, people with sensory difficulties (such as blind or deaf people), as well as those who, due to their life course, are transitorily conditioned (such as pregnant women), children and the elderly (Decreto-Lei nº163, 2006).

From these regulations we must retain some important information such as the following:

- It is recommended the timely evaluation of these same regulations impact on the actual reduction in the number of occurrences, and damage caused by possible urban and industrial fires/emergencies (RJ-SCIE, 2008);
- The definition of effective (of a building) as the "estimated maximum number of people that can occupy simultaneously a given space of a building or enclosure", (RJ-SCIE, 2008:7904).
- In an emergency, special attention should be given to the evacuation conditions, since the egress routes must be of adequate size, especially if there are occupants with mobility constraints (Decreto-Lei nº163, 2006).

In this dissertation industrial buildings and airport infrastructures are the only studied/analyzed types of buildings. Therefore, we considered pertinent to specify (in the following topics) some legal and mandatory parameters that refer information regarding only these two types of building. As shown in Table 3, safety and emergency evacuation parameters regarding airports and industrial buildings are regulated by RJ-SCIE and by RT-SCIE.

#### **Building Utilization-Types and Risk Categories**

The RJ-SCIE divides each building, according to the type of utilization of the building and according to the risk categories (taking into account a number of risk factors such as height and herd at risk, fire load and floors below the reference plane). Table 4 lists these different utilization-types (RJ-SCIE, 2008).

Table 4: Building Utilization-Types Definition (RJ-SCIE, 2008)

Building Utilization-Types	Building Utilization
Type VIII	Commercial Buildings, Transports Platforms and Terminals
Type XII	Industrial, Manufactory Buildings and Warehouses

Industrial buildings like production factories are considered to be a Type XII building that consist of buildings, parts of buildings or open air enclosures (that usually doesn't receive public occupants) for industrial activities or storage of materials, products or equipment, repair shops and all services auxiliary or complementary to these activities (RJ-SCIE, 2008).

Airport Terminals are considered to be a Type VII building and correspond to buildings or parts of buildings that receive public, occupied by commercial establishments where materials, products, equipment or other goods are exposed and sold (intended for consumption outside the establishment) or occupied by gates intended for access to means of transport by road, rail, sea, river or air (including intermodal troughs) as a space for interconnection between the public road and those means of transport, with the exception of outdoor shipping platforms (RJ-SCIE, 2008).

These regulations also classify buildings according to their fire risk level. For this parameter the RJ-SCIE divides buildings in risk places, as shown in Table 5, and in fire risk categories, defined according to Table 6 (RJ-SCIE, 2008).

Table 5: Risk Places Division (RJ-SCIE, 2008)

Risk Places	Definition
B	Local accessible to public and staff, with an effective >100 occupants and a public effective >50% of the occupancy, where 90% of the occupants don't have mobility impairments and where the risk of fire is low (aggravated by activities, produces, materials or equipment)
C	Place presents exacerbated risks of fire and the development of fire due either to the activities carried out therein, or to the characteristics of the products, materials or equipment therein, in particular the fire load

Table 6: Fire Risk Categories Classification (RJ-SCIE, 2008)

Fire Risk Categories	Definition
1 <sup>st</sup>	Low Risk
2 <sup>nd</sup>	Moderate Risk
3 <sup>rd</sup>	High Risk
4 <sup>th</sup>	Very High Risk

Industrial buildings are classified as a C risk place and of first, second, third or fourth fire risk category according with the parameters indicated in Table 7 (RJ-SCIE, 2008)

Table 7: Fire Risk Categories Classification for Type XII Buildings (RJ-SCIE, 2008)

Risk Classification Parameters for Type XII			
Risk Categories	Modified Fire Load	Buildings	Open Air Enclosures
		Number of Occupied Floors (Bellow the Reference Level)	Modified Fire Load
1 <sup>st</sup>	≤500 MJ/m <sup>2</sup>	0	≤1.000 MJ/m <sup>2</sup>
2 <sup>nd</sup>	≤5.000 MJ/m <sup>2</sup>	≤1	≤10.000 MJ/m <sup>2</sup>
3 <sup>rd</sup>	≤15.000	≤1	≤30.000 MJ/m <sup>2</sup>

	MJ/m <sup>2</sup>		
4 <sup>th</sup>	>15.000 MJ/m <sup>2</sup>	>1	>30.000 MJ/m <sup>2</sup>

Airports are classified as B risk place and as a first or second fire risk category according with the parameters indicated in Table 8 (RJ-SCIE, 2008):

Table 8: Fire Risk Categories Classification for Type VIII Buildings (RJ-SCIE, 2008)

Risk Classification Parameters for Type VIII			
Risk Categories	Height of the Building [m]	Number of Occupied Floors (Bellow the Reference Level)	Effective
1 <sup>st</sup>	≤9	0	≤100
2 <sup>nd</sup>	≤28	≤1	≤1.000

### Self-protection Measures

Self-protection measures are a group of actions and measures that intend to (ANPC, 2012):

- Prevent and control risks that may have a negative effect on people and goods;
- Respond properly to possible emergency situations;
- Ensure the implementation of these actions as instruments of emergency prevention.

In this sense, employers, owners, explorers of each building utilization type, condominium administrators or management entities of common spaces for various uses, such as Safety Officers (SO), should organize the self-protection measures and the management of SCIE in buildings and enclosures during its operation or use based on the following measures (RJ-SCIE, 2008):

- **Preventive measures:** may be prevention procedures or plans according to the risk category;
- **Intervention measures:** may be emergency procedures or internal emergency plans according to the risk category;
- **Safety records:** where auditing or inspection reports should be included, as well as a list of all maintenance actions and occurrences directly or indirectly related to SCIE;
- **Formation in SCIE:** raise awareness actions aimed to all the employees and collaborators of the exploring entities, or specific training formations for the SO and other elements that deal with situations of greater risk of emergency;
- **Evacuation drills:** test the internal emergency plan and train the occupants to create routines of behavior that improve the procedures in real emergency scenarios.

The mandatory self-protection measures for each utilization-type of building (Table 9) are the following (RT-SCIE, 2008):

Table 9: Self-Protection Measures for Each Building Utilization-Type (RT-SCIE, 2008)

Utilization-Types VIII and XII			
Self-Protection Measures	Fire Risk Category		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup> and 4 <sup>th</sup>
Safety Records	X	X	X
Prevention Procedures	X	-	-
Prevention Plan	-	X	X
Procedures in Case of Emergency	-	X	-
Internal Emergency Plan	-	-	X
Awareness Actions and SCIE Formation	X	X	X
Evacuation Drills	-	X	X

**2.3.3 Evacuation Drills**

In order to protect building occupants from unforeseen events, basic preventive measures should be adopted and it is necessary to develop and implement procedures aiming the prevention, protection and preparation for any emergency situation (MAPFRE, 1997).

Evacuation drills are carried out in different buildings to familiarize occupants with the evacuation procedures. In these drills, different types of emergencies, like fires, earthquakes, floods, bomb threats, can be simulated (MAPFRE, 1997).

Most of the occupants of a building enter and exit always through the same door, so paths and alternative exits may be unfamiliar, even if the occupant already knows the building for a long time. Evacuation drills provide the occupants the opportunity to locate and use paths and alternative solutions under non-hazardous conditions and help, likewise, familiarization with alarms and with appropriate procedures to adopt in emergency situations (MAPFRE, 1997).

In addition to preparing people for a possible threat, the evacuation drill also allows the confirmation or not of the correct operation of some of the facilities safety gear, such as smoke detectors, alarms, communication systems, and allows measurements of evacuation and intervention of emergency teams times too (MAPFRE, 1997).

Drills also provide their organizers data about occupants’ behavior and existing protection systems. Being well planned and well executed, drills are tools very effective to create safer

work environments. It may be stated that the behavior of workers improves gradually over several drills (Miguel, Góis, & Silva, 2010).

The preparation of a drill should be a conscious work and must consider eventualities that may arise during its implementation and the ability to collect a lot of information. A simulation carried out without sufficient preparation can lead to accidents. It should be simulated every possible emergency scenario with different levels of severity. Drills should be carried out, usually on an annual basis so the procedures are recalled and possible faults may be corrected (MAPFRE, 1997).

The conduct of evacuation drills aims to test and verify (ANCP, 2012):

- The effectiveness of the emergency response organization;
- The capacity of the people responsible for the response organization;
- The training of all staff of the institution/company in the response to an emergency situation;
- The appropriateness and dimensioning of the means and resources implemented;
- The adequacy of the operational procedures.

Only for guidance purposes, the following values can be considered as maximum times for an evacuation drill of any type of building (ANCP, 2012):

- 10 minutes for the total evacuation of the building;
- 3 minutes for the evacuation of each floor.

As a whole, it can be estimated that the total duration of an evacuation exercise should not exceed 30 minutes, for any building (ANCP, 2012).

### **Evacuation Drills Periodicity**

The maximum time between drills must be the ones listed in Table 10 (according to Portuguese legislation) When the occupants' characteristics make it impossible to carry out evacuation exercises, there should be exercises in frameworks to replace them and reinforced safety measures, particularly in the areas of fire monitoring and safety instructions (RT-SCIE, 2008).

Table 10: Evacuation Drills Periodicity (RT-SCIE, 2008)

Utilization-Type	Risk Categories	Maximum Time Between Drills [Years]
VIII and XII	2 <sup>nd</sup> and 3 <sup>rd</sup>	2
VIII and XII	4 <sup>th</sup>	1

## Types of Evacuation Drills

Evacuation drills can be organized according to its applicability and operability, as shown in Table 11 (ANCP, 2012).

Table 11: Types of Evacuation Drills (ANCP, 2012)

Type of Execution	
Organization	Preparation: Do not imply the displacement of human or material resources
	Operational: Execution of the planned activities. Safety teams and other elements involved in the process
Programming	With previous notice: Safety teams and other occupants are aware of the day and hour of the drill execution
	Without notice: Only the safety teams are aware of the day and hour of the drill execution

## 2.4 Airport Emergencies

An airport emergency is any occasion or instance, natural or man-made that warrants action to save lives and protects property and public health. Virtually no airport has sufficient resources to respond to every emergency situation independently (Port of Seattle, 2003).

Each airport must depend to some degree on the resources from its surrounding communities. It is essential to prepare for emergencies that face an airport to be able to respond quickly, efficiently and effectively. While every contingency cannot be anticipated and prepared for, a strong emergency preparedness program can assist in limiting the negative impact of these events, including liability and other post-emergency issues (Port of Seattle, 2003).

Because self-evacuation results in a catastrophic event several emergency response plans have been developed to facilitate the timely and appropriate response to emergencies occurring on or in the immediate vicinity of the airports. The principal goals of these plans are to render necessary assistance and minimize further injury and damage to persons and property involved in accidents or emergency situations at the airport. Evacuations can be classified in two types: spontaneous and deliberate (Port of Seattle, 2003):

- **Spontaneous evacuations:** occur when immediate life threatening incidents occur without warning, such as natural disasters, fires, explosions, actual or perceived acts of terrorism, both domestic and international, or other “no-notice” hazardous events;
- **Deliberate evacuations:** occur in response to hazardous or potentially hazardous conditions that are not recognized by the occupants of the airport as immediately life threatening but requires an evacuation to ensure their safety and security. Examples

of this are bomb threats, suspected Improvised Explosive Devices (IED), small fires, hazardous chemical spills and commercial airplane crashes on the ramp.

## 2.5 Passengers with Reduced Mobility

According to the US Department of Transportation (2013:2) “Individual with a disability means any individual who has a physical or mental impairment that, on a permanent or temporary basis, substantially limits one or more major life activities, has a record of such an impairment, or is regarded as having such an impairment”. As used in this definition:

- Physical or mental impairment, means (US Department of Transportation, 2003):
  1. Any physiological disorder or condition, cosmetic disfigurement, or anatomical loss affecting one or more of the following body systems: neurological, musculoskeletal, special sense organs, respiratory including speech organs, cardio-vascular, reproductive, digestive, genito-urinary, hemic and lymphatic, skin, and endocrine;
  2. Or any mental or psychological disorder, such as mental retardation, organic brain syndrome, emotional or mental illness, and specific learning disabilities.

The term physical or mental impairment includes, but is not limited to, such diseases and conditions as orthopedic, visual, speech, and hearing impairments; cerebral palsy, epilepsy, muscular dystrophy, multiple sclerosis, cancer, heart disease, diabetes, mental retardation, emotional illness, drug addiction, and alcoholism;

- Major life activities, means functions such as caring for one’s self, performing manual tasks, walking, seeing, hearing, speaking, breathing, learning, and working”.

To sum up “Disabled person” or “person with reduced mobility” means any person whose mobility when using transport is reduced due to any physical disability (sensory or locomotor, permanent or temporary), intellectual disability or impairment, or any other cause of disability, or age, and whose situation needs appropriate attention and the adaptation to his or her particular needs of the service made available to all passengers (US Department of Transportation, 2003).

Disabled people are not a homogenous group and have very different needs and some people will even have more than one disability. Some people are visibly disabled, such as someone who uses a wheelchair or a cane, but many have disabilities which are not immediately obvious, such as learning difficulties. Some symptoms of disabilities may be intermittent, such that individuals may be effectively disabled or have reduced mobility at one time and yet will appear to be capable at other times (Pires, C., Zorro S. and Silva J., 2015a).

### 2.5.1 Rights and Duties

Serving the needs of disabled people and people with mobility difficulties makes sense. It is estimated that around 20% of the United Kingdom (UK) adult population has some form of disability. Estimates are similar for Europe as a whole. There is also a close correlation between disability and age- nearly half of disabled people are over state pension age (Department of Work and Pensions, 2006).

The number of people over 65 years in Europe almost doubled between 1960 and 2001. By 2030 this group is expected to represent nearly a third of the total population. People who are either disabled or older, or both, will represent around 35% of the future European population. With higher expectations among that group for travel, there is a necessity to start changing airports services, facilities and of course emergency plans (European Commission, 2003).

Based on the principle that the single market for air services should benefit all citizens without exception, access to air transport for people with disabilities, reduced mobility, disability, age or any other factor (under conditions comparable to those of other citizens) is a concern at Community level. Thus, Regulation (EC) n°1107/2006 of the European Parliament and of the Council (published on July 5<sup>th</sup>), concerning the rights of disabled persons and persons with reduced mobility when traveling by air, main objective is based on ensure the provision of necessary and appropriate assistance to the specific needs of these citizens. In this regard, there is a legal requirement for transport of disabled persons and persons with reduced mobility, except when safety reasons prescribed by law justify the refusal, and the same should not be refused on grounds of disability (Jornal Oficial da União Europeia, 2006).

UK airports are covered by the rules in the Equality Act of 2010, therefore facilities and information to help moving quickly and easily around the airport that can be used by everyone whatever their needs are, must be provided. Contact customer services at the airport must be done if a disabled passenger needs help to move through the airport from check-in, through security to the departure gate. Assistance should not be charged and if their flight is changed, the airport should still make reasonable efforts to try and help them (The National Archives, 2010).

In Portugal, regulation about provision of assistance at airports (regulated by the National Civil Aviation Authority-ANAC) also refer that the airport managing bodies are responsible for assisting the disabled and handicapped and may, for this purpose, provide such assistance at the airports they manage (ANAC, 2008).

Moving along the airport, the airport has legal duties to help PRM in their arrival at the airport such as (UK Citizens Advice Bureau, 2015):

- Make sure airport they have arrived and if necessary meet them at an agreed meeting point. This could be either inside or outside the terminal;
- Help PRM to move from the meeting point to the check-in, taking them through passport control, customs and security checks, settle them into their seat, get them off the aircraft, etc., until they get to a point where they can carry on with their journey; the airport staff must also help them to get connecting flights, with baggage and with reaching a toilet.

### **2.5.2 Infrastructural Obstacles**

Many disabled persons or persons with reduced mobility do not request specific assistance, either because they are independent or because they are travelling with an assistant. It is particularly important for these people that the airport environment is designed to be 'user-friendly' and easy to navigate. From the first phase of planning of new public buildings or when refurbishing the existing ones, airport managing bodies should ensure that the needs of disabled persons and persons with reduced mobility are central to the design brief. This should include early involvement of local access/disability groups and engagement of an access consultant (ABCB, 2013).

The Australian Building Codes Board (ABCB) recently stated that every Australian has the right to feel confident that they will be able to evacuate from a building in a safe and independent manner should the need arise because of an emergency event. In fact, this is a right of all people with disability in any country that has ratified the United Nations (UN) Convention on the Rights of Persons with Disabilities. The Convention outlines these obligations, including a requirement to ensure the rights to safe egress in an emergency. It also outlines responsibilities to consider the principles of 'universal design'. This Convention lists general obligations, including the requirement to (ABCB, 2013):

- Undertake or promote research and development of universally designed goods, services, equipment and facilities;
- Promote their availability and use and universal design in the development of standards and guidelines.

It is also important that seating areas reserved for disabled persons and persons with reduced mobility should have signage to discourage able-bodied persons from using it (ABCB, 2013).

### **2.5.3 Emergency Situations**

According to the Principle 6 of the Dublin Declaration on 'Fire Safety for All' in Buildings people with activity limitations who occupy or use a building frequently must be included in all practice fire evacuations, in order to learn the skill of safe independent evacuation to an accessible place of safety remote from the building. During a real emergency incident, evacuation assistance provided by other building users or rescue by firefighters, and the time

spent waiting for that assistance or rescue in the building must be kept to an absolute minimum. People with activity limitations must be actively encouraged to participate in fire safety preparatory planning and regular practices and, without exception, must be consulted and included in all activities concerning their own evacuation from a building. Management systems and emergency protection measures in buildings are never 100% reliable. People with activity limitations must, therefore, be actively encouraged to be self-aware in situations of risk, and facilitated in learning the skill of self-protection (Walsh, 2015).

According to airports evacuation plans if emergency evacuation assistance is needed, disabled passengers must be advised verbally that their supervisor needs to be aware of their need of assistance. The airports also request that disabled passengers inform the Airport Emergency Manager that they have requested assistance during an evacuation so that planning is done to ensure they are evacuated (Port of Seattle, 2003).

Every single day airports and authorities receive thousands of complaints from passengers without disabilities; for passengers with reduced mobility traveling by plane is even harder and the special services do not work as it should. The EU conducted interviews to PRM about the services provided at airports and their main difficulties since the acquisition of a ticket to the landing and airport exit. The major faults mentioned were the difficulty of orientation since there is no proper signage to this group of passengers (e.g. signaling for the blind and people with learning disabilities) and that this signaling is not easy to understand (eg. for elderly passengers), and the lack of basic information. The passengers above the age of 65 who were interviewed also indicated that they had almost never been seen as a disabled passenger and that this is a major flaw by airports since this group of people has motor, visual, auditory difficulties and more propensities for diseases that prevent the full performance of some basic activities. They all left clear that airlines need to recognize people with disabilities as consumers, not as exceptions (European Commission, 2015). All of these issues are also mentioned in a recent investigation work where PRM services from two airports were analysed, proving that this PRM service is insufficient and frail and that these two airports level of accessibility should be improved (Gaspar, 2016).

The worst airport fire in German history occurred on April 11<sup>th</sup>, of 1996, when flames broke out in the busy Düsseldorf airport, quickly filling the terminal with acrid, toxic smoke. Travelers frantically looked for exit signs. In the ensuing chaos, 17 people died and 150 were injured. A spokesman for the Düsseldorf fire brigade, quoted in European news accounts, blamed the high number of casualties on passengers "ignoring" emergency exit signs. For airport management, having the signage singled out as a contributor to the disaster underscored the importance of maintaining a clear communications system in a crowded, public space. Prior to the fire, signage at Düsseldorf had become a clutter of airline logos and retail and service ads, with directional signs lost in the cacophony. "After our fire disaster, we knew we needed to make better signage and we needed to show passengers that Düsseldorf was making a fresh start," says Olaf Ebbrecht, a strategic planner at the airport; "We wanted

to create an image that shows that we are creating something new and better than our former days" (Corporate Design Foundation, 2015:1). Following a devastating fire, Germany's Düsseldorf airport urgently needed a clear, easy-to-read signage system. Traveler safety and ease of movement were key considerations, along with establishing a distinct identity for the airport (Corporate Design Foundation, 2015).

## 2.6 Accessibility Solutions

The main flaws mentioned in the previous topic can be solved when some of the measures presented next are correctly implemented. The Figure 3 illustrates which are the solutions for the major flaws.

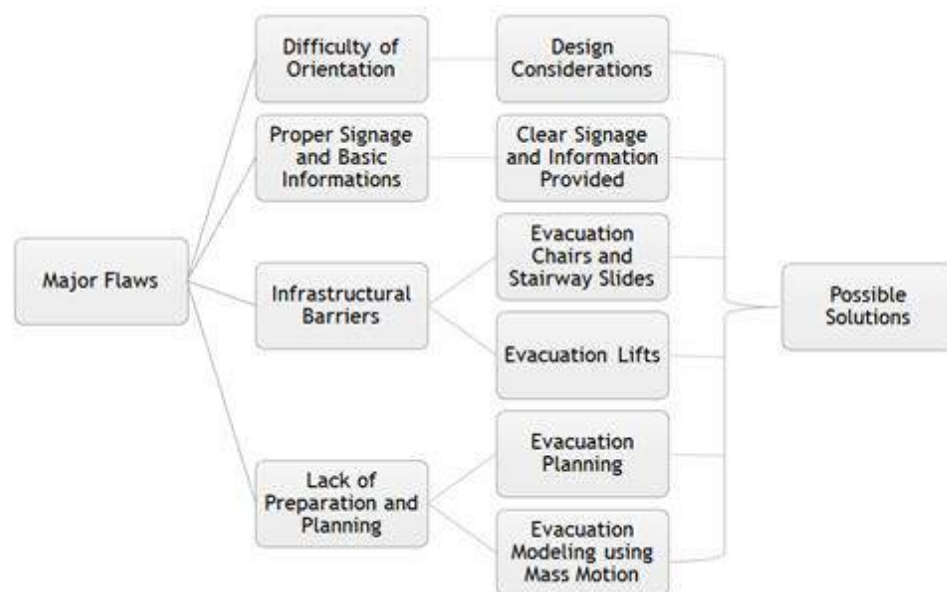


Figure 3: Major Flaws and Possible Solutions (Pires, Zorro & Silva, 2015b)

### 2.6.1 Evacuation Planning

During an evacuation, the building's anatomy changes, alarms are activated, passenger lifts cannot generally be used and people use egress paths that may differ from their normal path into the building. For these reasons, designing a universally accessible means of egress into the building at an early concept stage is the best approach. In terms of universal design and evacuation planning, there are several measures that can be implemented to ensure a building is safe for all occupants, not only when the building is being used in its normal state, but when there's an emergency and a need for evacuation. The following list aims to provide some basic steps that can be adopted to provide a universally inclusive environment and with regard to emergency planning (Wilson, 2015a):

- Ensure emergency management procedures are in place, with mechanisms to identify the needs of individuals and conduct regular inspections of egress routes to ensure they're unobstructed and nominate fire wardens in all locations who can supervise the evacuation and remove any barriers;

- Implement tailored Personal Emergency Evacuation Plans (PEEPs) for people who self-identify their impairment and develop General (or Group) Emergency Evacuation Plans (GEEPs) within public spaces;
- Provide clear and unambiguous exit signage with Braille and tactile characters, with directional signage directing people to exits and accessible means of egress path that can be negotiated independently, including the use of an evacuation lift when on an upper or lower level;
- Use assistive devices such as evacuation chairs where evacuation lifts have not been provided, use supplement alarm notification systems with visual and vibrating alarm devices and provide accessible handrails on both sides of all fire stairs;
- Display evacuation diagrams showing the accessible egress routes, including identifying where exits, evacuation lifts, refuge areas, evacuation chairs and fire stairs are provided and identify exit doors with a contrasting color and provide accessible door handles and sufficient circulation space on approach to each exit door.

#### **2.6.2 Signage and Information Provided**

When passengers with reduced mobility (PRM) arrive at the airport, signage should be clear and unambiguous to enable them to find their way easily to the correct part of the airport and to continue their journey. This is significant because airports are complex structures on large campuses, and orientation and wayfinding can be challenging for those who are unfamiliar with the terminal. The need for simplicity and ease of orientation is even more important due to the inherent time-pressure and stress involved in air travel (Stannis, 2007).

Everyone arriving at an airport should be able to identify easily and quickly where they need to go and how to get there. Designing the signage and way finding systems with the needs of disabled people in mind - including those with learning disabilities or vision loss - will ensure that all passengers, regardless of disability, more easily understand the signage. It is important that airport managing bodies understand their obligation to involve disabled users throughout the process to validate possible accessible design options. Information about the layout and facilities at an airport, including specific facilities and services for disabled passengers and passengers with reduced mobility, should also be available on airports' websites for passengers to consult before their journey (Stannis, 2007).

Basic information to be provided at the arrival/departure points could include a map of the relevant airport terminal(s) and a list of key facilities, such as check-in areas, toilets and restaurants and include such things as average walking times from departure lounges to gates and any obstructions such as steps or narrow doorways. The information displayed should follow guidance on accessible signage. Although provision of tactile mapping or Braille signage could also be considered in relation to the UK Disability Discrimination Act (DDA) duty to

make reasonable adjustments, it is more likely that passengers with a visual impairment would seek information orally from the arrival/departure point. For this reason, a telephone will be required where the point is not staffed (The National Archives, 1995).

Signage should be clear, intuitive and unambiguous. Wherever possible pictograms should be used and where appropriate, tactile symbols should be used where the sign is within reach of passengers, for example at toilet facilities (Port of Seattle, 2003).

The graphic and wayfinding design should aim to develop a “common language” throughout the terminal “campus”, and should include multiple cues to facilitate communication, including supplementary visual and tactile cues. Graphic and text information should be presented with maximum contrast for legibility and should consider color blindness and good color rendition in interior environments. With the aging population, clarity, color contrast, eliminating glare, tactile lettering, and locating signs at logical locations, all combine to make signs easier to read for all (Stannis, 2007).

A very interesting example of a new approach on airport signage is the new Narita International Airport’s third terminal that opened on april 8<sup>th</sup>, 2015, in Japan; a terminal solely dedicated to Low Cost Carrier (LCC) airlines. Adhering to a low cost philosophy also the Terminal 3 design was handled on a budget and costed approximately half of the usual amount. Therefore, to cut costs the designer opted to not install the usual moving walkways and illuminated signs and implemented running tracks with signage for user-friendly guidance (Figure 4 and Figure 5), (Thomas, 2015).



Figure 4: Narita International Airport Terminal 3 Signage (Thomas, 2015)



Figure 5: Narita International Airport Terminal 3 Signage Details (Thomas, 2015)

The designers also refereed that the key to the architecture and design is consolidating two (or more) functionalities into one in pursuit of economic reasonability (Thomas, 2015).

The company *Jensen Hughes* also provides an overview of new dynamic exit signage technology (Figure 6 and Figure 7) that aids passenger evacuation in the case of emergency events (Jensen Hughes, 2016).



Figure 6: Dynamic Emergency Signage (Ferreira, 2016b)

The typical airport system of emergency exits is designed based on the prevailing building and fire codes, which assume a distributed evacuation of passengers using the closest exit during an emergency event. The number of exits, their location, and their exit capacity are based on a set of prescriptive rules designed to minimize the number of passengers using an individual exit as well as the travel distance to each exit. With fire/emergency in mind as the determining event, the exit paths are designed so that if fire and smoke block one exit at least one alternative exit path is available. To provide a safe path to exit, emergency lighting is typically required, and a system of illuminated 'Exit' and 'Running Man' signs are provided to mark the path to each exit as well as each exit itself. The traditional system of exit marking may be adequate for a fire event, but it leaves much to be desired for other emergency events where distributed use of all the exits may not be desirable (Ferreira, 2016):

- **Fires involving an aircraft, or occurring during refueling operations:** could make exiting via one or more exits that lead to the tarmac extremely hazardous. It would therefore be desirable to indicate that these exits should not be used to evacuate;
- **Severe weather event:** may lead to passenger evacuation from the concourses back to the main terminal, or to designated refuge areas within the airport;
- **A bomb threat, explosion, or active shooter event occurring on the landside of the terminal:** may warrant evacuation of passengers using the tarmac exits only, as well

as a desire to prohibit passenger re-entry from the air side to the land side of the terminal.

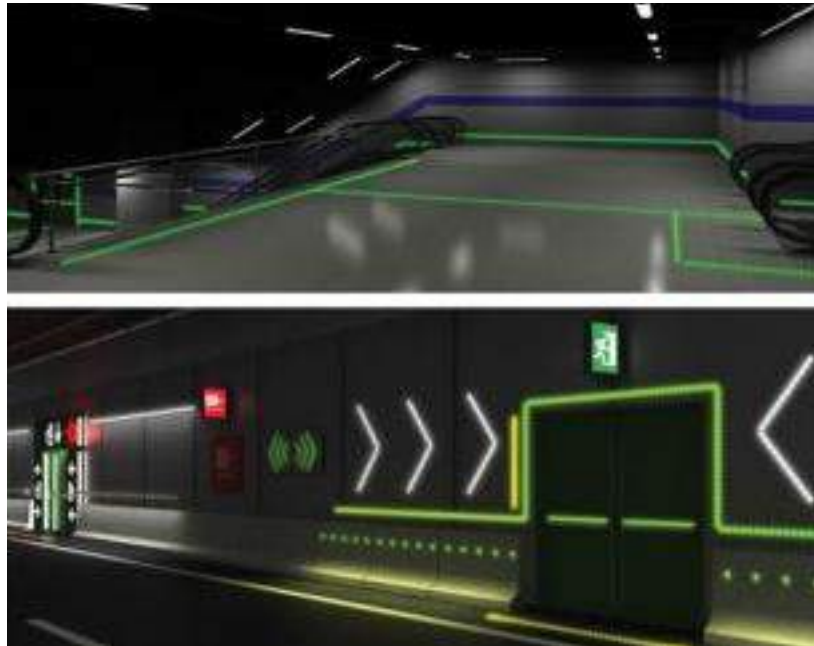


Figure 7: Dynamic Emergency Signage for Exit Routes and Exit Doors (Ferreira, 2016)

For each of these events, airports would currently have to depend on staff intervention or audible announcements through the airport's mass notification system to instruct passengers which exits they should and should not use during the event. The implementation of this new type of signage may decrease the evacuation times significantly and make the passengers wayfinding/orientation easier (Ferreira, 2016).

For people who are deaf or hard of hearing the equipment needs to be compatible with hearing aids, have variable amplification for those who do not use a hearing aid, and some kind of visual indication to confirm that requests for assistance have been received. Language for this group of people should be simple and clear, with appropriate illustrations. In line with the DDA, all reasonable steps should be taken to ensure that such information is made available in alternative media such as large print, audio formats or computer disk and visual alarms. Although demand may be lower than for other formats, it would be good practice to have Braille versions available on request, particularly for documents which have a wide circulation and whose content does not change frequently (The National Archives, 1995).

### 2.6.3 Design Considerations

There are several factors that influence the decision and the desire to travel common to all persons, such as personality, lifestyle, socio-economic and cultural characteristics. For PRM there is still a lack of accessibility to external barriers and obstacles that can be found in the respective infrastructures. Awareness of the needs of passengers with disabilities and the ability to communicate them effectively is an important step in removing barriers such as lack

of information about accessibility and accessible facilities (Gaspar, S., Zorro, S., & Silva, J. 2015).

Transportation systems, specially air transport, present some obstacles to passengers with reduced mobility, although there is legislation requiring the adaptation of airport infrastructures and aircraft for the safe and comfortable transportation of these passengers (Gaspar, S., Zorro, S., & Silva, J. 2015).

Detail attention needs to be paid to the selection of flooring materials. Apart from having to address maintenance and durability, the floor needs to be slip-resistant for the benefit of all passengers but particularly those with mobility-related disabilities. The use of contrasting colors, values, patterns and textures can supplement wayfinding for people with disabilities and supports an intuitive orientation process for all users. Consistent use of the same flooring materials and colors at key locations such as the entrances to washrooms and elevators, as well as at the tops and bottoms of stairs and escalators helps those with visual disabilities to orientate themselves in a large building such as an airport. One of the more challenging tasks for any designer is to weigh the merits and demerits of “hard” versus “soft” flooring. Hard surfaces tend to help those with visual disabilities, as sound provides important feedback, but for those with hearing disabilities, hard surfaces increase impact noise and therefore ambient noise, which has a detrimental effect on their ability to differentiate important auditory information (Stannis, 2007).

The respect for the dignity of the PRM should be preserved, and this is best done by making it possible for them to use the same facilities and routes as other passengers by providing equitably information and accessibility. Great progress has already been made in making physical provision by ramps, large lifts, minimizing changes of level and aids in wayfinding. Now it is important to start implementing some of these helpful design initiatives (Kazda & Caves, 2015):

- **For the blind:** synthesized voice calling out the floor and direction in all elevators and tactile maps of the terminal;
- **For the visually impaired:** high contrast flight information displays, high contrast wayfinding information embedded in the flooring and audible warnings;
- **For the deaf:** visual paging systems displaying text versions of audio announcements and telecommunication devices for deaf in terminals;
- **For the hard of hearing:** amplified handsets on counters, induction loops and public phones with sound boosters;
- **For all requiring caregivers:** unisex washrooms in every cluster of washrooms.

Recommendations for symbols to cope with the language problem have been set, and almost all airport groups have their own brands of shapes, colors and fonts, each specific to a type of sign. The signs can be static (for emergency instructions) or dynamic (for check-in, flight, gate, bag claim and car parking information). These signs should not be at least more than

10° from the natural line of vision and the lettering should be at least 1 cm high for every 3 m viewing distance. Despite these aids to design, some people still must ask the way (Kazda & Caves, 2015).

Cultural differences are other contributors to wayfinding difficulties, while the emotional state also influences people ability to decode and use the information to assist in the wayfinding process. There is also the problem of avoiding clutter with too many signs. The Vancouver airport terminal uses lighting graduated in brightness towards the nodes for wayfinding and uses the light fittings and carpet markings as pointers too. Some other airports provide helpful indications of the time required to reach places as seen in Figure 8 (Kazda & Caves, 2015).



Figure 8: Vancouver Airport Terminal Signage Example (Kazda & Caves, 2015)

Airports must also designate points at which disabled persons or persons with reduced mobility can announce their arrival at the airport and request assistance (see Figure 9), (Kazda & Caves, 2015).



Figure 9: Point of PRM Arrival at Airport (Kazda & Caves, 2015)

#### 2.6.4 Evacuation Helpers/Devices for PRM

“In case of emergency use the stairs”. This sentence poses a significant risk for the 20% of the population with some form of disability, particularly the 10,5% with a mobility disability when

the options for evacuation in a multi-level building are generally limited to stairways only. This is even more important for the 0,6% of the population that uses a wheelchair (Wilson, 2015b).

Conventional passenger lifts can be very unsafe places during a fire and are not to be used in an emergency unless under direction from the fire brigade. It therefore raises the question: how would a person with mobility limitations get to an exit level if they're located on an upper or lower level when the alarms sound? There is an urgent necessity of the creation of alternatives to elevators and escalators.

The *EVAC-CHAIR* (Figures 10 and 11) is designed to carry incapacitated people down stairs in an emergency evacuation when the lifts are not working. The *EVAC-CHAIR* is portable and no installation or modification of stairways is required. It also allows fast emergency evacuation, travels up and down stairs safely, nobody needs to be carried, no congestion is added in fire escapes and it is easily operated by one person (URHSS, 2015).



Figure 10: *EVAC-CHAIR* Design (EVAC-CHAIR, 2015)



Figure 11: *EVAC-CHAIR* Glide Down Stairs and Rolls Across the Floor (EVAC-CHAIR, 2015)

The Occupational Health and Safety Act require employers to provide for all persons, including staff and visitors with disabilities, to be evacuated speedily and without panic in an emergency. They are normally saved near stairway or elevators although most of the airports and other buildings don't have any type of evacuation chairs (SADL, 2015).

There has been discussion over recent years as to a suitable quantity and distribution of evacuation chairs within a building. Ultimately this is a decision to be made by the building owner and/or occupants, in terms of risk management and any foreseeable cost/benefit.

Bruyère and Stothers (2002) recommend that an evacuation chair is provided on each floor for every person who would need one during an evacuation and it has been common practice to provide these within the refuge area or near the fire escape stairwell (Bruyère & Stothers, 2002).

The recommended number of evacuation chairs has also suggested being one chair for up to 2% of the building occupants, plus one chair per known person with disability per floor (Suttell, 2003).

Based on ABCB data, quoting 0,6% of the population using a wheelchair, 2,5% of the population using a mobility aid and 10,5% of the population with a mobility disability, this distribution of evacuation chairs might be a little low. Consideration as to the use of the building is also a critical factor in determining the required number. Despite the huge help that this chair represents to passengers with reduced mobility it still is insufficient because the passenger relies on the help of another passenger to use the evacuation chair and in an emergency situation it is complicated to receive that help from an unknown. This chair is easy to use to descent buildings but not when you are in underground levels and want to go to upper levels to exit the building (ABCB, 2013).

Some buildings like hospitals, homes for senior citizens, shopping centers and houses with many floors are starting to add slides in stairways for people with motor difficulties descent faster and without help of another person (Figure 12).



Figure 12: Stair Slide (Altamash, 2015)

As all other existing infrastructures for the exclusive use of handicapped these slides may be misused by normal people since nothing prevents them from doing so. This implies that the people who really need to use them are prevented from doing so and end up have no other choice but to wait for someone else's help (Altamash, 2015).

Obviously, passenger lifts provide an opportunity to move large numbers of people quickly to an exit level. Over the last four decades, there has been a growing consensus that tall buildings must consider the use of specially designed and constructed evacuation lifts - a lift that can be used during an emergency, for self or assisted egress - as part of an integrated egress strategy. It has been widely acknowledged that the use of evacuation lifts will speed up an evacuation and can be an important part of a means of egress for all occupants, not

just those with a disability. Internationally, the use of evacuation lifts is becoming more commonplace and necessary as buildings reach new heights (ABCB, 2013).

Skyscrapers are increasingly getting taller and buildings have now reached a height where it's no longer reasonable to expect occupants to use the fire stairs as part of the means of egress. Extremely tall buildings make it difficult, if not impossible, for emergency services personnel to carry equipment up the stairs. Occupant demographics are also changing. People now struggle when evacuating via stairs as people need to constantly rest, resulting in a slower evacuation. This was an observation from survivors of the 9/11 evacuations of the World Trade Center and will become an ever increasing concern as we grapple with an ageing population and longer working lives (Wilson, 2015b).

When discussing egress solutions for people with disability, the Australian Building Codes Board recently declared that lifts were seen to offer obvious accessibility advantages over other options for occupants with disability. However, the ABCB recognized that there continues to be reluctance internationally to legislate requirements for evacuation lifts in new buildings (ABCB, 2013).

In 2013, the ABCB released a non-mandatory handbook providing guidance when developing performance-based 'alternative solutions' adopting an evacuation strategy that includes the use of lifts. The handbook provides advice on lift designs, including consideration for clear and unambiguous Braille and tactile accessible signage on landings, fire and smoke protection for landings, smoke detection and management in lift shafts, reliable power supplies, reducing water damage as well as emergency management procedures. Evacuation lifts that consider the principles of universal design must be considered in all future high-rise buildings. These buildings will also need to develop emergency management procedures that adopt a holistic or integrated approach to the safe evacuation of all building occupants (ABCB, 2013).

This integrated evacuation strategy will provide for a more inclusive approach to disability egress provisions. Ultimately, adoption of an inclusive approach to evacuate all building occupants, regardless of their abilities, will benefit everyone (ABCB, 2013).

## **2.7 Emergency Evacuation Simulation Models**

Evacuation modelling using a 3D pedestrian tool lets designers adopt unconventional fire-safe designs. In a conventional sense, buildings have been designed based on prescriptive means of escape recommendations adopted from various building regulations and codes. However, with current and future buildings becoming more bespoke, the application of traditional prescriptive fire safety recommendations can prove restrictive. Analyzing evacuations can be done using hand calculations that consider people movements as a hydraulic flow. But when the complexity of the building and its crowd movements increase such calculations become very difficult (Oasys, 2015).

Thus, the use of performance-based design in the form of evacuation modelling can be greatly beneficial. Evacuation modelling allows building designers to use bespoke and unconventional designs, while maintaining a high level of fire safety for occupants. It simulates human behavior in emergencies, based on crowd dynamics and pedestrian movement within a defined geometry, and can be applied to a wide range of buildings, infrastructure and events. With mass motion we can replay the results in 3D at any time, making it very easy to show how the building operates in normal operation or during an evacuation (Oasys, 2015).

Once the evacuation drills are costly activities, companies/entities eventually realize them at most once a year. Accordingly, limitations on the drills reliability in respect to the building evacuation capacity or structure may exist and, therefore, other support tools to study the evacuation of buildings were created (Meacham, 1997).

Evacuation calculations are increasingly becoming a part of performance-based analyses to assess the level of life safety provided in buildings. In some cases, engineers use hand calculations to assess life safety, and in others, computational evacuation models are used (Meacham, 1997).

Hand calculations usually follow the equations given in the Society of Fire Protection Engineers (SFPE) Handbook to calculate mass flow evacuation from any location within the building (Gwynne, Galea, Lawrence, & Filippidis, 2008).

On this type of calculation, the occupants are assumed to be standing at the doorway to the egress component on each floor as soon as the evacuation begins and we focus mainly on points of constriction throughout the building (commonly the door to the outside, transitions between egress components, or where different paths merge together) and calculate the time for the occupants to move past these points and to the outside (Kuligowsky, Peacock, & Hoskins, 2010).

The occupants are treated as particles that follow known rules and factors such as density, interactions with other individuals, the building conditions (including fire effects), and the decision-making processes of the individuals are ignored (Kuligowsky et al., 2010).

Therefore, to achieve a more realistic evacuation calculation and simulation, or a more efficient solution, engineers have been looking to evacuation computer models to help assess key aspects of a building's life safety attributes. Currently, there are many evacuation models to choose from, each with unique features. In order to understand better the features of each software the comparison between three models advantages and disadvantages is made in the next paragraph:

- **MassMotion:** model created by Oasys is the most advanced pedestrian simulation and crowd analysis tool available. However, this is not an open source model and its license is extremely expensive (Oasys, 2015);

- **Pathfinder:** model created by *Thunderhead Engineering*. It is an advanced simulation tool that allows the importation of computer aided design (CAD) models and specific data from fires and earthquakes. It also allows introducing disabled occupants and generates visual results (video). This is an open source model that is freely available to academic studies (Thunderhead Engineering, 2015);
- **EVACNET4:** model created by Thomas Kisko (University of Florida). It is a paid software that does not allow the importation of CAD models, fire data or the insertion of disabled occupants. It also doesn't generate visual results (Kisko, Francis, & Nobel, 1998).

These models can range from an efficient use of the hand calculations (thus having the same limitations mentioned above) to models that have complex equations and occupants with decision-making capabilities. NIST developed a report where each egress model was reviewed according to the information provided on a series of evacuation modeling categories. The features of the egress models were divided in two major categories: the main features and the special features (both summarized in Annex 1), (Kuligowsky et al., 2010):

- **Main features:** describe the model's availability status, purpose (as it pertains to modeling certain building types), validation strategies, and internal modeling techniques of which the user should be aware before choosing the model for a project. Internal modeling techniques include the method of moving occupants, the method of simulating occupant behavior, the incorporation of fire effects, and the method of structuring the building within the model;
- **Special features:** specific aspects of evacuation models that the user may be interested to simulate for certain specific scenarios.

The evolution of the techniques of computer graphics and computer animation, coupled with new methods of numerical analysis, without forgetting the evolution of capacities and speed of processing, have led in the last two decades to the appearance of many simulators in which this graphic capacity is well patent (Kuligowsky et al., 2010)

However, the quality of the results is debatable. There is no real data to calibrate and validate these simulation models, and the few data that exist have led to different results (Averill & Mileti, 2005).

Although the level of graphical results obtained by the most advanced simulators is visually spectacular, difficulties exist in the validation of the values obtained and therefore there are differences for equal scenarios obtained in different simulators (Figure 13). The type of simulations performed is not easily reproducible, the actual known cases are sparse and the elements reduced to allow conclusions and the calibration of these tools and, therefore, reliable data are needed for this purpose (Korhonen & Hostikka, 2010).

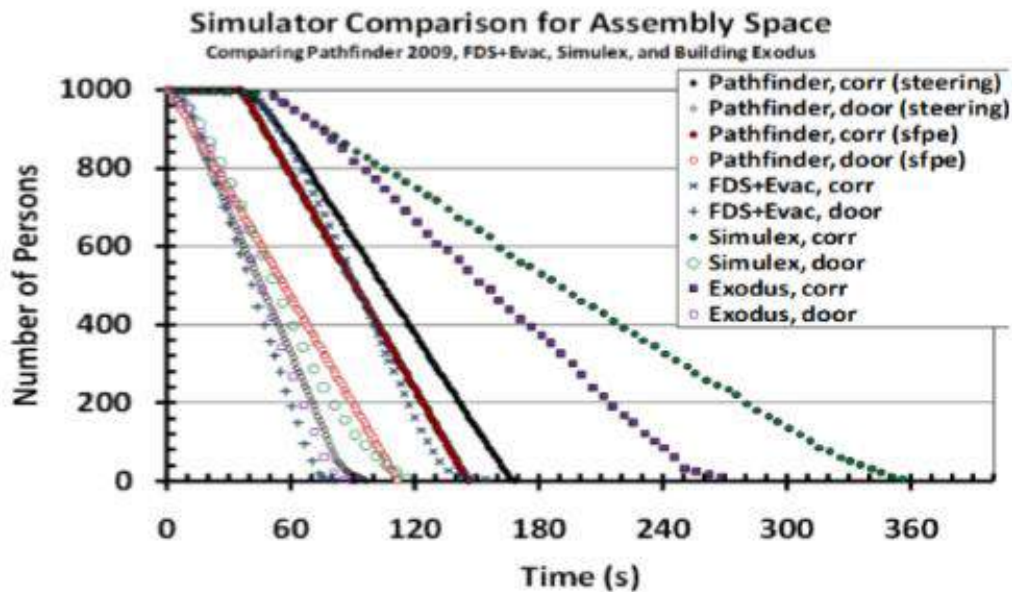


Figure 13: Differences of Evacuation Simulation Tools (Korhonen & Hostikka, 2010)

A possible source of data comes from the analysis of evacuation drills, recreations of real situations through scenarios that do not reproduce the actual conditions of an emergency (such as stress, and the stress inherent in an emergency). That is, the drills that have been carried out involve limited scenarios in space and number of participants and the laws that have been deduced, either of movement or those that try to reproduce the human behavior, are obtained from these drills. Therefore, when using these simulation tools in situations of greater complexity, deviations between results can be large. However, there are no easy or simple ways to validate this data (Averill et al., 2005; (Averill & Mileti, 2005; Korhonen & Hostikka, 2010).

## 2.8 Conclusion

Emergency evacuation can be necessary anytime, anywhere. Thus, buildings must have unambiguous and efficient evacuation plans that concern the need of all its occupants and it is important to understand that infrastructural factors, human behavior and mobility impairments influence the course of an evacuation.

Passengers with reduced mobility are not usually add in regard when an evacuation plan is done and the procedures in those plans are not implemented, but some existing alternative egress measures to people with disabilities may improve evacuation times.

The number of laws, codes and standards regarding building safety and evacuation is huge because each nation/country implements their own laws/codes and because a general/unified international mandatory regulation does not yet exist.

Evacuation simulation tools are extremely helpful to simulate evacuations when it is impossible or extremely expensive to perform drills. They also allow the user to understand

better evacuation procedures and simulate alternative scenarios to search better evacuation routes. However, unfortunately, these simulators are not calibrated and so the results obtained in its simulations may not be trustworthy.

## Chapter 3 - Evacuation Simulation Tool: *Pathfinder*

### 3.1 Introduction

The high manufacturing production and the complex nature of certain buildings make it impossible to carry out evacuation drills and performing these drills in non-working hours severely affect its results.

Simulation models of emergency evacuations can have enormous practical and scientific payoffs, not only for the social sciences but also for other sciences such as engineering and public health. However, simulation models can realize their full potential as a tool for emergency planning and intervention only if they are inextricably linked to fieldwork and empirical investigations of emergency evacuations that would provide computer scientists and mathematicians with the appropriate parameters for social behavior. Thus, their future is multi-disciplinary, involving the expertise of computer scientists, engineers, fire scientists, social scientists, and emergency planners, among others.

As mention in the first chapter of the current study the use of evacuation simulation tools allows obtaining results of virtual evacuation drills without any intervention in the building in question. In this chapter a specific evacuation simulation tool is analyzed, describing some of its definitions and basic features, and the validation case definition and its results are presented.

For the validation process, we got recent drills reports and evacuation data from a company (validation case). This information was inserted in the simulation software and we obtained some results. These results were compared with those available in the company reports.

Depending on the difference between the results it was possible to validate the tool allowing its use for the analysis of a case study in Chapter 4.

### 3.2 Evacuation Simulation Tool: *Pathfinder* Basics and Definitions

*Pathfinder* 2015 and *Pathfinder* 2017 (released in January of 2017) were the evacuation simulation tools used in this dissertation. *Pathfinder* is an agent based egress and human movement simulator that provides a graphical user interface for simulation design and execution as well as 2D and 3D visualization tools for results analysis. It is a product of *Thunderhead Engineering* and its features and specifications are resumed in Annex 2 (Thunderhead Engineering, 2015, 2017).

This is an open source (provides a six-month free license for academic use/research only) simulation tool and a very user-friendly model that allows the simulation of disable occupants. These were some of the main reasons why it was chosen to be used as our tool.

Some of the most important concepts and parameters of *Pathfinder* are defined on the following topics.

### 3.2.1 Creating Movement Space

The main egress components include rooms (empty floor spaces bounded by walls), doors (connect rooms on the same level), stairs or ramps (connect rooms on different levels) and elevators (connect multiple levels). In *Pathfinder* (Thunderhead Engineering, 2015, 2017):

- Rooms can have any polygonal shape and can never overlap on the same level;
- Doors can be thick (if they are occupying a doorway - the area between two rooms) or thin (if they are simply connecting two touching rooms). Occupants cannot pass between two rooms unless they are joined by a door and the simulation tool requires that each occupant must have a path to at least one exit door. In simulation results doors provide useful flow measurements. Some doors' special features are:
  1. **One-way door:** occupants can only travel through it in one direction. However, occupants can ignore the one-way setting of doors if their profile has "Ignore One-way Door Restrictions" checked (this allows them to go through in either direction);
  2. **State:** by default, all doors are always open throughout the simulation but this parameter allows the initial state of the door to be specified as well as additional timed states.
- Stairs or ramps are always rectangular and implicitly contain a thin door on each end to connect the adjacent rooms;
- Elevators can be any shape and can travel in any direction.

### 3.2.2 Creating Occupants

#### Profiles

Occupants are defined in two parts: profiles and behaviors. With a profile, we can assign the occupant specific parameters (Figure 14).

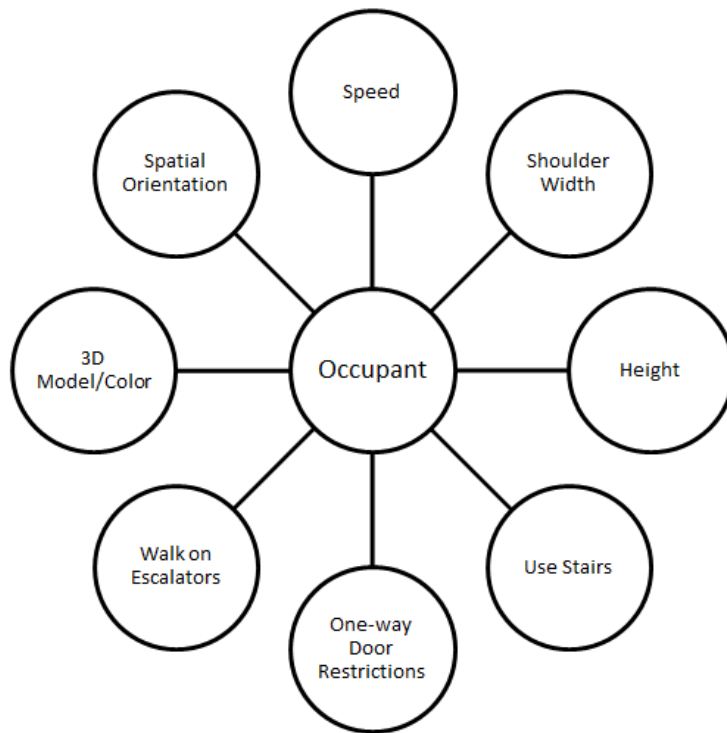


Figure 14: Occupant Editable Profile Parameters

Where (Thunderhead Engineering, 2015, 2017):

- **Priority level:** priority values are completely relative and higher values indicate higher priority. This allows occupants of lower priority to move out of the way of those of higher priority and this would be useful when simulating first responders that must be able to move easily through a crowd of occupants;
- **Ignore one-way door restrictions:** whether the occupant will ignore (when checked) the direction specified for one-way doors.

Considering that simulations in this tool will include several types of occupants, some standard characteristics were researched.

The Confederation for Fire Protection Associations in Europe (CFPA-E) listed some velocities for the average walking speed of human beings in horizontal and vertical surfaces (Table 12 and 13) that are recommended to be used in modeling (CFPA-E, 2009).

Table 12: Average Walking Speeds for Horizontal Surfaces (CFPA-E, 2009)

Subject Group	Velocity [m/s]
No Locomotion Disability	1,25
Elder (< 65 Years)	0,45
Children (>6 Years)	0,45

Crutches	0,94
Walking Stick/Cane	0,81
Rollator/Hiker	0,57
Electric Wheelchair	0,89
Manual Wheelchair	0,36
Assisted Manual Wheelchair	1,30
Assisted Ambulant	0,78

Table 13: Average Walking Speeds for Vertical Surfaces (CFPA-E, 2009)

Subject Group	Velocity [m/s]	
	Ascent	Descent
No Locomotion Disabilities	0,7	0,7
Crutches	0,22	0,22
Walking Stick/Cane	0,35	0,32
Rollator/Hiker	0,14	0,16

There are also some standard values in literature for the shoulder width that are represented in Figure 15:

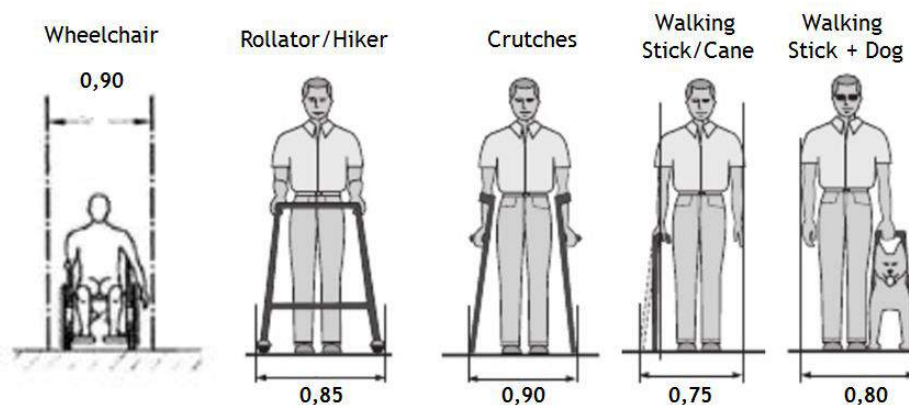


Figure 15: Shoulder Width of Different PRM Types (in meter), (EMBRATUR, 2001)

### Behaviors

Represent a sequence of actions the occupant will take throughout the simulation. For each behavior there is an implicit action to move the occupant to an exit and this implicit action

will always happen; last and intermediate actions may also be added that can make the occupant wait or travel to a non-exit destination, such as a room or point (Figure 16).

By default, there is a behavior in the model called “Go to Any Exit” that makes the occupant move from their starting position to any exit present in the model by the fastest route.

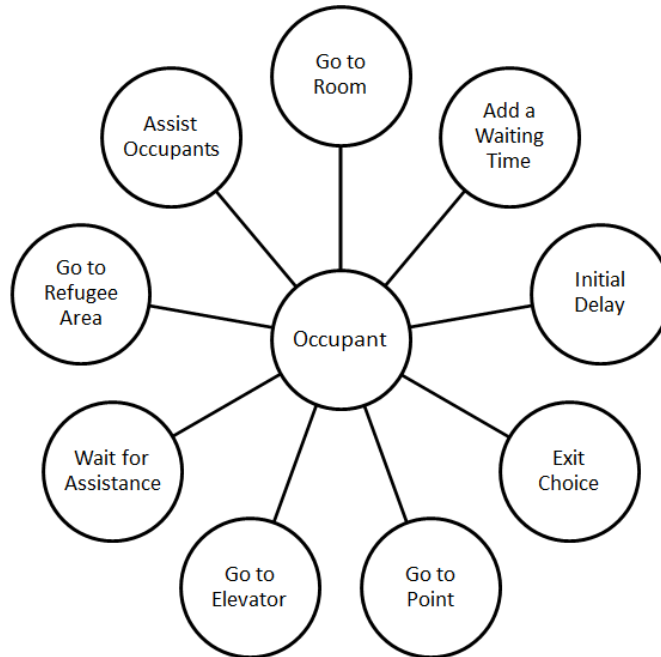


Figure 16: Occupant Editable Behavior Parameters

We can specify the following parameters (Thunderhead Engineering, 2015, 2017):

- **Initial delay:** specifies an initial delay that makes the occupant wait at their starting position before moving to the next action;
- **Exits:** specifies a set of exit doors the occupant can exit through.

### 3.3 Pathfinder Validation Case

Considering the objectives of this work and the unavailability of specific and validating data comparable with the results obtained in the simulations, the validation of the simulation tool, in a building where previous simulations data were known, became necessary. The main goal of this validation is to simulate an evacuation drill (according to, already effectuated, evacuation drill reports), compare the simulation tool results with the evacuation drill reports and conclude if the tool simulates a scenario close to reality.

Knowing that it is a company that meets the safety and buildings evacuation current legislation in Portugal, and have trusted and quality data of evacuation drills, *Joalpe-Exhibitors Industry, SA* was chosen to be the case for validation of the evacuation tool (Joalpe, 2016).

### 3.3.1 Characterization of Validation Case

The *Joalpe-Exhibitors Industry, SA* (Figure 17), referred from now on in this dissertation as *Joalpe*, was established in 1984 and is a producer of a wide range of plastic products such as coat hangers, shelves, articles in plastic for exhibitors, innovative shopping car, among many others, and a new line of wood products (cutting and manufacturing torn panels and kit furniture) and plastic profiles (extrusion), (Joalpe, 2016).



Figure 17: *Joalpe* (Joalpe, 2016)

The company's facilities used as validation case are located in Tortosendo Industrial Park, in Covilhã (Portugal), and are composed of two buildings/units: The Plastic Unit (with two floors) and the Wood Unit (Figure 18) (Joalpe, 2016).

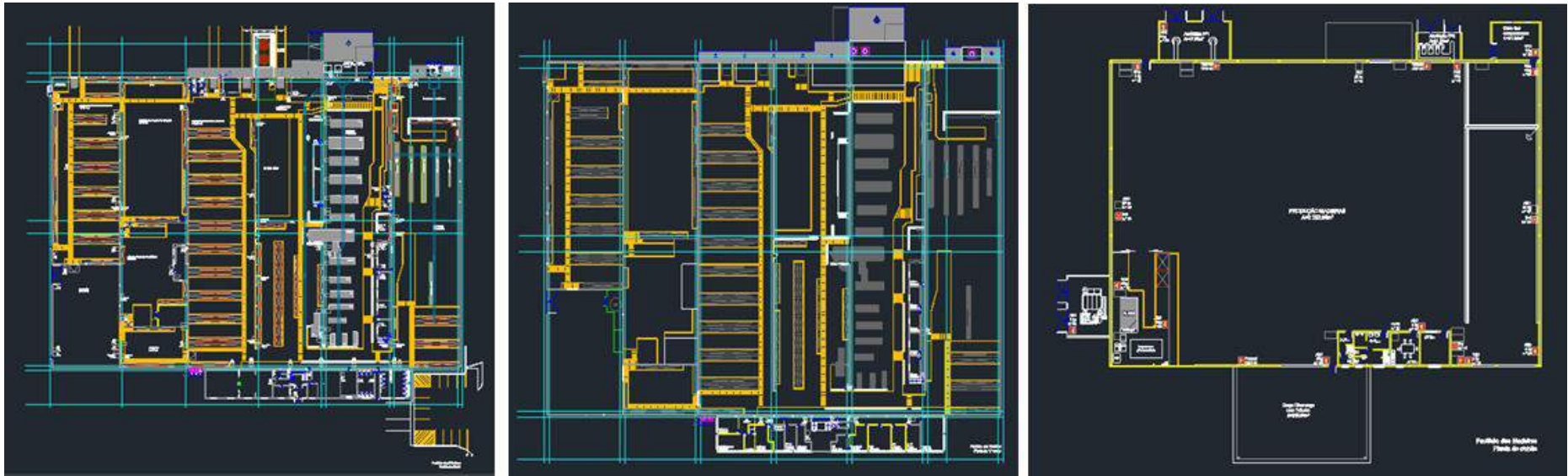


Figure 18: *Joalpe's* Plastic Unit (Ground and First Floor) and Wood Unit, respectively (Joalpe, 2016)

### 3.3.2 Validation of the Simulation Features

The validation of the evacuation simulation tool was made according to the following methodology, in Figure 19.

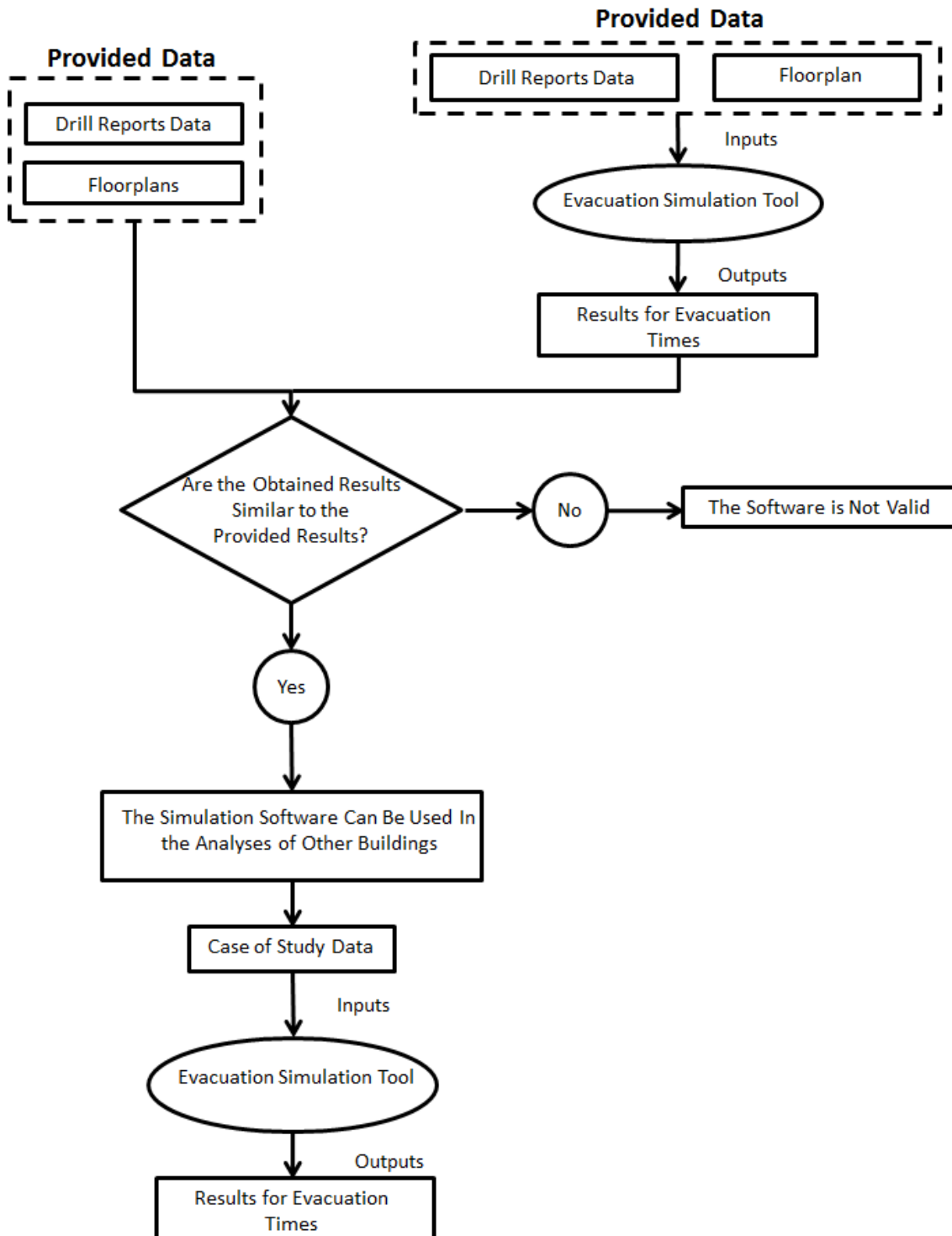


Figure 19: Validation Case Methodology

Thus, with the buildings' floor plans and the evacuation drill reports the distribution of occupants in buildings and the behaviors assignment were made.

In this validation case, three characteristics remain equal in any evacuation drill: the profile of the occupants, the characteristics of the Plastic Unit stairs and the exits of the two buildings.

The occupants in these simulations are represented as cylinders (or 3D Models) and have all the same average walking speed, height and shoulder width. They are also all allowed to use stairs and to ignore all the one-way door restrictions. Figure 20 and Annex 3 sum up all these features.

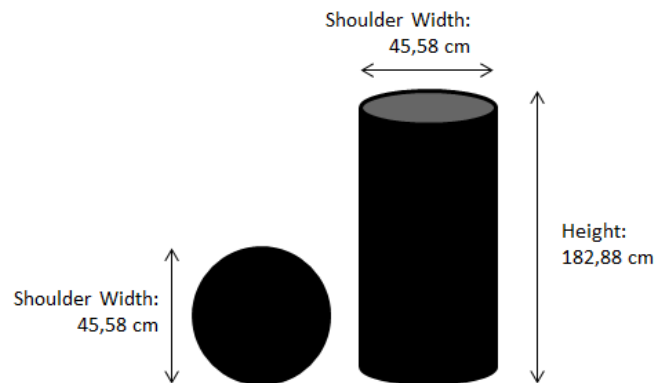


Figure 20: Validation Case Occupants' Profile Features

In the two units there is just one stair - in the Plastics Unit, that was named "Stair1". This stair is composed by 2 pieces ("Stair1\_1" and "Stair1\_2") with the characteristics indicated in Figures 21 and 22.

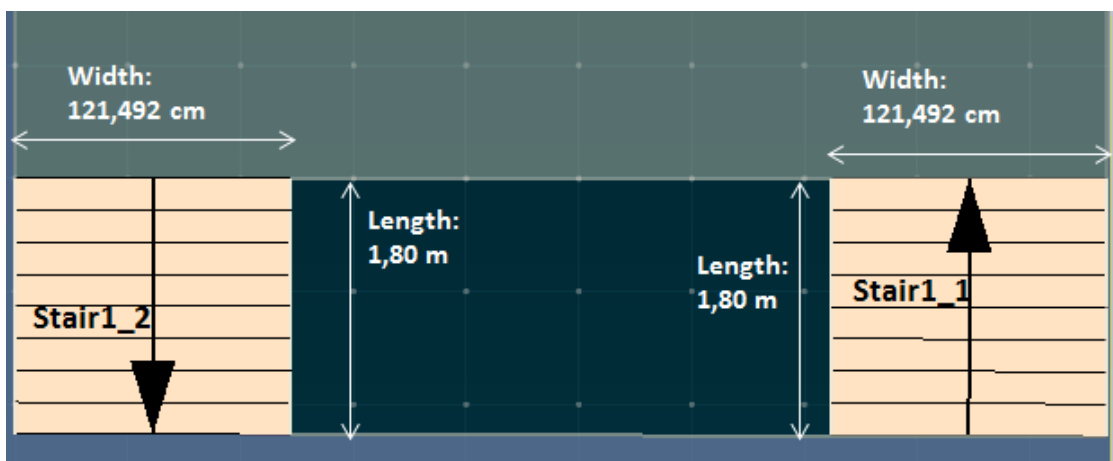


Figure 21: Joalpe Stairs' Features



Figure 22: *Joalpe* Stairs' Features (Risers)

In the two buildings there are two types of emergency exits: the main doors and the emergency doors. The Plastic Unit has one main door and seven emergency doors and the Wood Unit has one main door and one emergency door. The main doors are always open and the emergency doors are always open but have a one-way restriction. Their features are specified in Annex 3 and their location is signed in Figure 23.

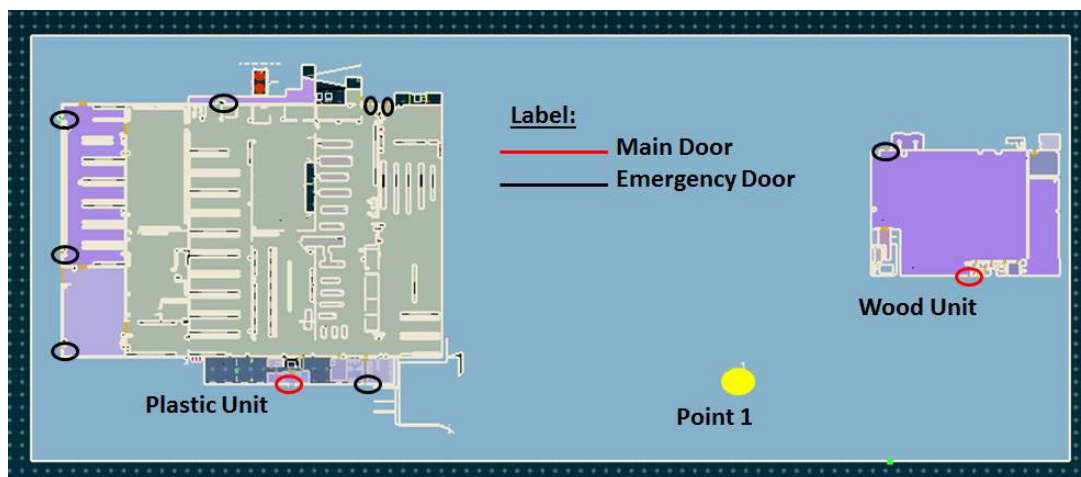


Figure 23: *Joalpe* Exit Doors Location

Although *Joalpe* provided us data for the preparation of six validation cases, in the next session only two cases of validation are presented, as an example, and the remaining four are described in Annex 3 of this document. However, in the analysis of results, it was decided to present the results of the six validation cases for respective and best analysis and understanding. Six validation cases may seem too much but this gave us more confidence in the final results; that is the reason why all the *Joalpe* drill reports were used.

### 3.3.2.1 First Validation Simulation: Drill n°1

In the report of Drill n°1 the values for the times in the gathering point were not registered. Thus, we saw an opportunity to make a detailed evaluation of the time that the occupants take to abandon the building (evacuation time). Drill n°1 occurred, with workers notice, on february 18<sup>th</sup>, 2013, in a general shift, by 08h06m and at that time 29 occupants were in the

building (all workers without mobility impairments). According to this report, the Drill n°1 occupants recognized the emergency 87,6 s after the drill start, then they selected an exit door and left the building. This drill acted as an awareness raising action so there were no affected zones or blocked doors. The following flowchart (Figure 24) sums up this drill behavior. In Annex 3 its specific features are provided.

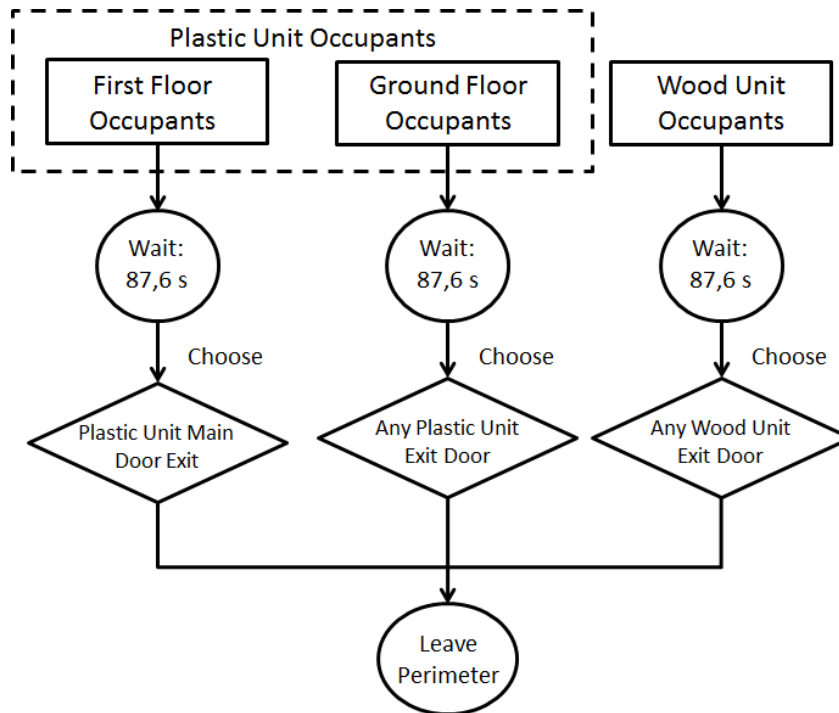


Figure 24: Joalpe Drill n°1 Occupants' Behavior

With the parameters regarding this validation case and the drill defined before, the geometry obtained in the simulation tool is that of Figure 23.

### 3.3.2.2 Second Validation Simulation: Drill n°2

Drill n°2 occurred on October 3<sup>rd</sup>, 2013, in a general shift by 15h00m and at that time 54 occupants were in the building (all workers without mobility impairments). This drill occurred with workers notice and 2 workers did not participate in the drill to guarantee the operation of the production line. According to this drill report, the workers recognized the emergency 148,8 s after the beginning of the drill, then they selected an exit door and went to gathering point ("Point 1") where a count of the occupants was made (lasted 124,2 s) and then they were authorized to leave the perimeter. In this drill an injured existed near the extrusion machine n°130, in the Plastic Unit, (at "Point 2") and three occupants recognized him 72,0 s after the drill start and helped the injured to go to the meeting point ("Point 1"). This drill worked as a work accident action where there were no affected zones or blocked doors. The following flowchart (Figure 25) sums up this drill behavior. In Annex 3 its specific features are provided.

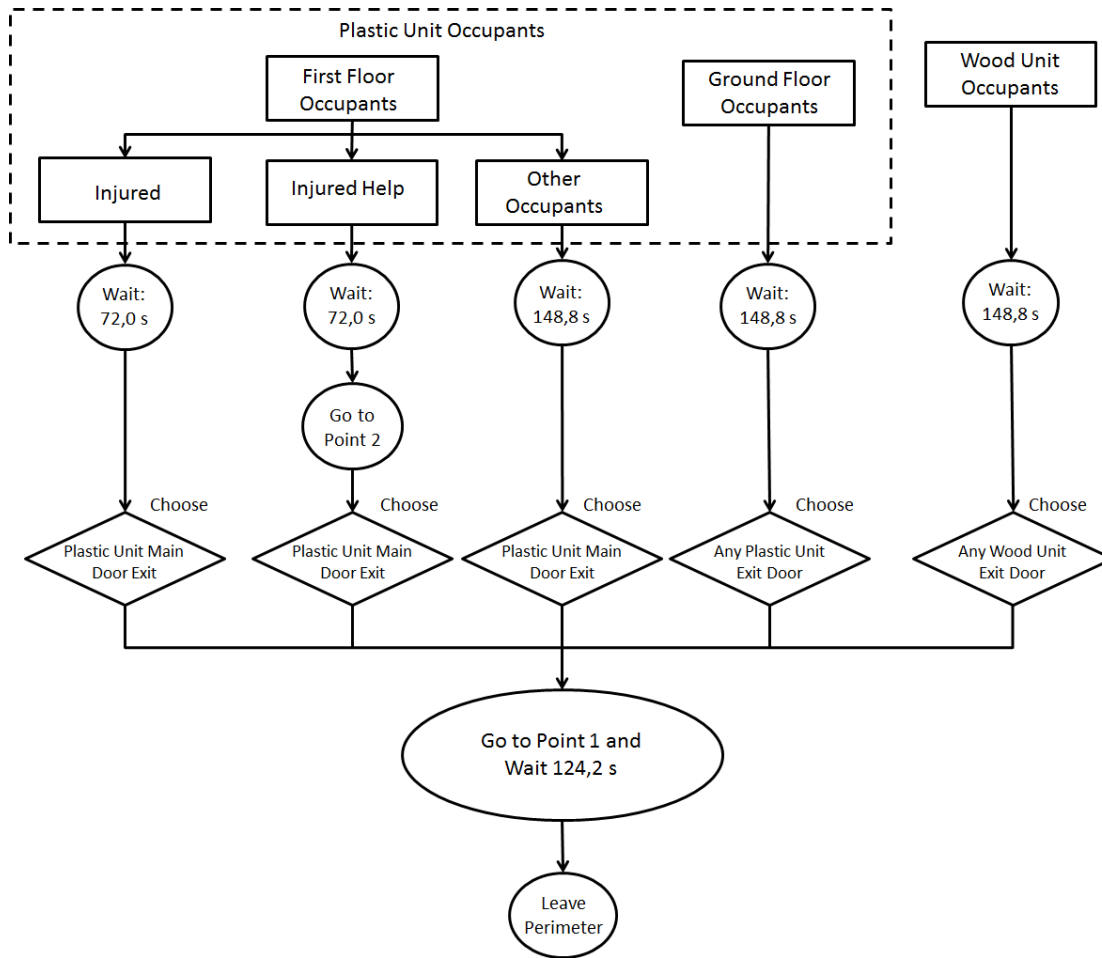


Figure 25: Joalpe Drill n°2 Occupants' Behavior

With the parameters regarding this validation case and this drill defined before, the geometry obtained in the simulation tool is that of Figure 26.

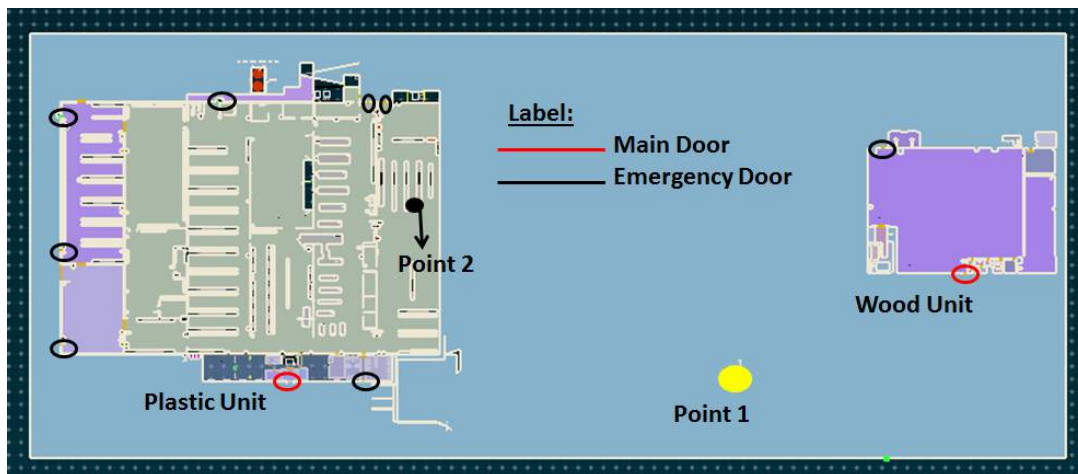


Figure 26: Drill n°2 Pathfinder Geometry Mesh

### 3.3.3 Validation Results

The first drill reported results (*Joalpe* data) and the first simulation tool results (obtained in *Pathfinder*) are very similar with only a difference of 52,8 s (13,77 %) for the evacuation time

and 18,5 s (3,01 %) for the drill duration time. Table 14 shows the results that were obtained by the drill reports, the results obtained in *Pathfinder* and the difference between them. Three values of times were compared/obtained where:

- $t_{\text{evac}}$  = time of evacuation;
- $t_{\text{drill}}$  = time of the drill duration;
- $t_{\text{drill}_{\text{recog}}}$  = time of emergency recognition by the occupants.

Table 14: *Joalpe* First Validation Results

	Drill n°1 Reported Results	Drill n°1 Simulation Tool Results	Difference between results of Drill n°1	
	[s]	[s]	[s]	[%]
$t_{\text{drill}}$	615,0	596,5	18,5	3,01
$t_{\text{evac}}$	383,4	330,6	52,8	13,77
$t_{\text{recog}}$	150,6	150,6	0,00	0,00
				40 Occupants

The second drill reported results (*Joalpe* data) and the second simulation tool results (obtained in *Pathfinder*) are very similar with only a difference of 62,7 s (16,13 %) for the evacuation time and 9,1 s (1,48 %) for the drill duration time. Table 15 shows the results that were obtained by the drill reports, the results obtained in *Pathfinder* and the difference between them. Five values of times were compared/obtained where:

- $t_{\text{evac}}$  = time of evacuation;
- $t_{\text{drill}}$  = time of the drill duration;
- $t_{\text{drill}_{\text{count}}}$  = time of occupants' count in meeting point;
- $t_{\text{drill}_{\text{recog}}}$  = time of emergency recognition by the occupants;
- $t_{\text{injured}_{\text{recog}}}$  = time of injured recognition by the occupants.

Table 15: *Joalpe* Second Validation Results

	Drill n°2 Reported Results	Drill n°2 Simulation Tool Results	Difference between results of Drill n°2	
	[s]	[s]	[s]	[%]
t_evac	388,8	326,1	62,7	16,13
t_drill	606,0	615,1	9,1	1,48
t_drill_count	124,2	124,2	0,00	0,00
t_drill_recog	148,8	148,8	0,00	0,00
t_injured_recog	72,0	72,0	0,00	0,00
54 Occupants				

The third drill reported results (*Joalpe* data) and the third simulation tool results (obtained in *Pathfinder*) are also very similar with only a difference of 52,8 s (13,77 %) for the evacuation time and 18,5 s (3,01 %) for the drill duration time. Table 16 shows the results that were obtained by the drill reports, the results obtained in *Pathfinder* and the difference between them. Three values of times were compared/obtained where:

- $t_{\text{evac}}$  = time of evacuation;
- $t_{\text{drill}}$  = time of the drill duration;
- $t_{\text{drill}_{\text{recog}}}$  = time of emergency recognition by the occupants.

Table 16: *Joalpe* Third Validation Results

	Drill n°3 Reported Results	Drill n°3 Simulation Tool Results	Difference between results of Drill n°3	
	[s]	[s]	[s]	[%]
t_drill	615,0	596,5	18,5	3,01
t_evac	383,4	330,6	52,8	13,77
t_recog	150,6	150,6	0,00	0,00
40 Occupants				

The fourth drill reported results (*Joalpe* data) and the fourth simulation tool results (obtained in *Pathfinder*) are, once again, very similar with only a difference of 24,7 s (4,45%) for the evacuation time and 42,1 s (5,39%) for the drill duration time. Table 17 shows the results that

were obtained by the drill reports, the results obtained in *Pathfinder* and the difference between them. Five values of times were compared/obtained where:

- $t_{\text{evac}}$  = time of evacuation;
- $t_{\text{drill}}$  = time of the drill duration;
- $t_{\text{drill}_{\text{count}}}$  = time of occupants count in meeting point;
- $t_{\text{drill}_{\text{recog}}}$  = time of emergency recognition by the occupants;
- $t_{\text{injured}_{\text{recog}}}$  = time of injured recognition by the occupants.

Table 17: *Joalpe* Fourth Validation Simulation Results

	Drill n°4 Reported Results	Drill n°4 Simulation Tool Results	Difference between results of Drill n°4	
	[s]	[s]	[s]	[%]
$t_{\text{evac}}$	555,0	530,3	24,7	4,45
$t_{\text{drill}}$	739,2	781,3	42,1	5,39
$t_{\text{drill}_{\text{count}}}$	168,0	168,0	0,00	0,00
$t_{\text{drill}_{\text{recog}}}$	91,2	91,2	0,00	0,00
$t_{\text{injured}_{\text{recog}}}$	375,6	375,6	0,00	0,00
68 Occupants				

The fifth drill reported results (*Joalpe* data) and the fifth simulation tool results (obtained in *Pathfinder*) are very similar with only a difference of 0,2 s (0,06%) for the evacuation time and 0,1 s (0,02%) for the drill duration time. Table 18 shows the results that were obtained by the drill reports, the results obtained in *Pathfinder* and the difference between them. Four values of times were compared/obtained where:

- $t_{\text{evac}}$  = time of evacuation;
- $t_{\text{drill}}$  = time of the drill duration;
- $t_{\text{drill}_{\text{count}}}$  = time of occupants count in meeting point;
- $t_{\text{drill}_{\text{recog}}}$  = time of emergency recognition by the occupants.

Table 18: *Joalpe* Fifth Validation Simulation Results

	Drill n°5 Reported Results	Drill n°5 Simulation Tool Results	Difference between results of Drill n°5	
	[s]	[s]	[s]	[%]
t_evac	327,6	327,8	0,2	0,06
t_drill	551,4	551,5	0,1	0,02
t_drill_count	46,2	46,2	0,00	0,00
t_drill_recog	80,4	80,4	0,00	0,00
16 Occupants				

The results of Drill n°6 simulation, a preview obtained in *Pathfinder*, and the results of the Drill n°6 obtained in the real executed drill, and reported later by *Joalpe*, are very different with a difference of 414,5 s (86,35%) for the time of the first occupant to reach Point 1 and 600,1 s (66,68%) for the time of the last occupant to reach the gathering point (“Point 1”). Table 19 shows the results provided in *Joalpe* report, the results obtained with the software and the difference between them. Thus, three times are presented, where:

- t<sub>evac</sub>= time of evacuation;
- t<sub>first</sub>= time of the first occupant to reach Point1;
- t<sub>last</sub>= time of the last occupant to reach Point1.

Table 19: *Joalpe* Sixth Validation Simulation Results

	Results of the Drill n°6 Simulation	Drill n°6 Obtained and Reported Results	Difference between results of Drill n°6	
	[s]	[s]	[s]	[%]
t_evac	513,8	-	-	-
t_first	65,5	480,0	414,5	86,35
t_last	299,9	900,0	600,1	66,68
62 Occupants				

### 3.4 Conclusion

With the data provided by *Joalpe* (drills reports, buildings' floorplans and evacuation plans) it was possible to validate the software. This validation (as mentioned in Chapter 1) was made by comparing the times obtained with the *Pathfinder* simulation model with the times reported in the drills reports provided by *Joalpe*.

As can be seen in Tables 14 to 18 (excluding Drill n°6), it is clear that the times for the drills simulations only differ in a few seconds, or do not differ at all in some cases, from the times reported by *Joalpe* (being 16,11% the biggest difference, for Drill n°2). It is presumed that these differences can be explained by the fact that the exact position of each occupant in the buildings, at the initial time of the incident, is not known (since it is not recorded in any document made available by the company).

From the sixth validation case (Table 19) two main results were found. The first is that the results differed so much because while in the *Pathfinder* simulation the emergency sound signal was issued immediately and the occupants reacted immediately to the warning and started their egress route, in the actual/real situation the emergency fire signal was not triggered and, consequently, not detected by the occupants causing each one to begin their egress from the building much later than predicted/simulated. However, it is important to safeguard *Joalpe* that, in accordance with the rules and self-protection measures in force, requested, before the simulation takes place, the inspection of the fire detectors and alarms to a competent entity.

The second conclusion is that although this validation case was not a success, this type of simulation tool proves to be excellent not only to aid in the preparation of simulations scenarios (since they allow simulating all kinds of scenarios), but also to be used in the early stages of construction or reconstruction/reconfiguration projects.

Once performed the analysis of the results, we can conclude that the simulation model *Pathfinder* generates, quickly and easily, valid and reliable results. Thus, the software validation is successfully confirmed. Once these results are validated, it is possible to use this tool in a case study/infrastructure where data, like that provided by *Joalpe*, are introduced and analyzed.

Thus, it is important to underline that without the validation of the software (*Pathfinder*) it shouldn't be used to simulate our case study, but since *Joalpe* collaboration it is/was possible to prove that the results obtained with this tool are reliable, and so it will be possible to apply this tool in our case study, in the next chapter, that is, in an airport infrastructure.



## Chapter 4 - Case Study

### 4.1 Introduction

In Chapter 3, *Joalpe* provided drills' results were compared with results obtained in *Pathfinder* for the same specific drills. Because the difference between the real results and the *Pathfinder* results is acceptable, the *Pathfinder* results are valid and the case of study can be analyzed with this tool.

Once fulfilled the first sub-objective of this work, the second sub-objective is fulfilled in this chapter. The main objective of this research is to analyze the influence of some factors (infrastructural and behavioral) in the movement of PRM and non-PRM through a building.

An airport receives thousands of passengers per day and the number of passengers with reduced mobility received is incoming day-by-day. Because of the dimension of these types of buildings and the consequent financial impact, drills (including staff and passengers) are not executed or when they are they only include partial areas and not the all airport infrastructures. Thus, in this chapter, an airport terminal is defined as a case of study and analyzed with an evacuation simulation tool.

Five simulation scenarios are studied and its results are all presented in images and flowcharts for a better understanding. In the annexed CD, videos of the results are available.

### 4.2 Terminal A- Case Study Definition

Terminal A is a departure airport terminal like some other existing airport terminals around the world. This terminal has a total (occupable) area of 8.773,333 m<sup>2</sup> and it is composed by two floors: the first floor is a restricted floor for the terminal staff and the ground floor is composed of two waiting areas for passengers with basic services, a check-in zone of a boarding gates zone, a foreign and borders area, and some other restricted areas for staff. According to *Pathfinder*, that can evaluate the maximum occupancy of a room, the terminal has a maximum capacity of 2.500 occupants - as it will be explained. All geometry and occupants were made having as reference airports and airport terminals, located around the world and data of public domain not corresponding, therefore, to any particular case.

Terminal A geometry was created in a design software named *RevitArchitecture* provided by *AutoDesk* (AutoDesk, 2015). These views are represented (in 3D) in Figure 27 and Figure 28 and in Figure 29 and Figure 30 is represented the room division where colors show different types of rooms. In Annex 4 all the room characteristics and legends (where the numbers represent a room) are listed as well as more 3D views of Terminal A.

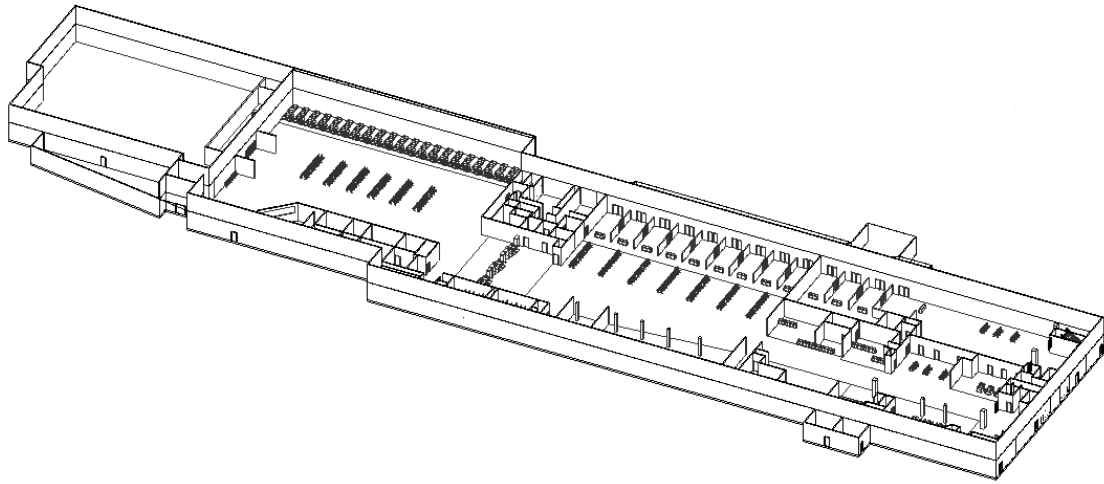


Figure 27: Terminal A 3D Front Interior View (without Roof, Ceilings and Hidden First Floor)

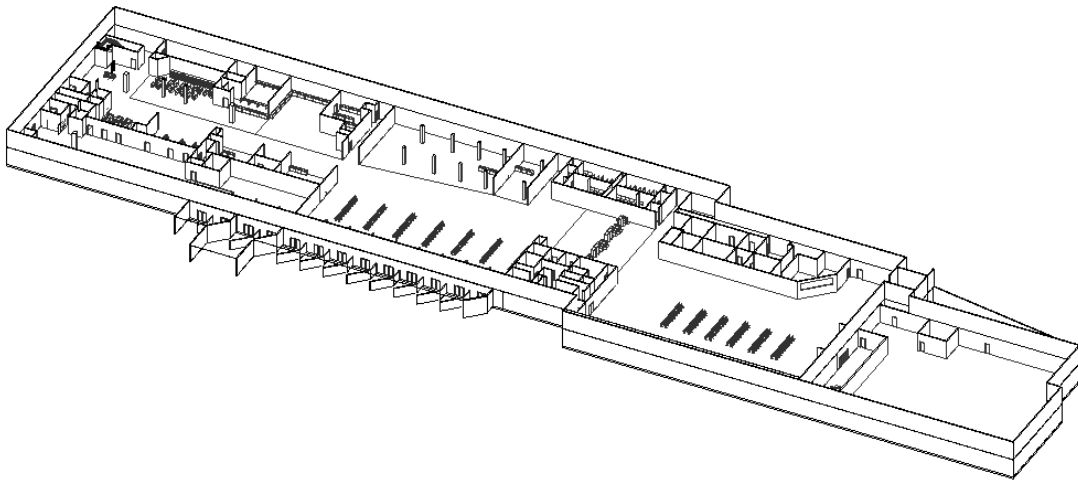


Figure 28: Terminal A 3D Back Interior View (without Roof, Ceilings and Hidden First Floor)

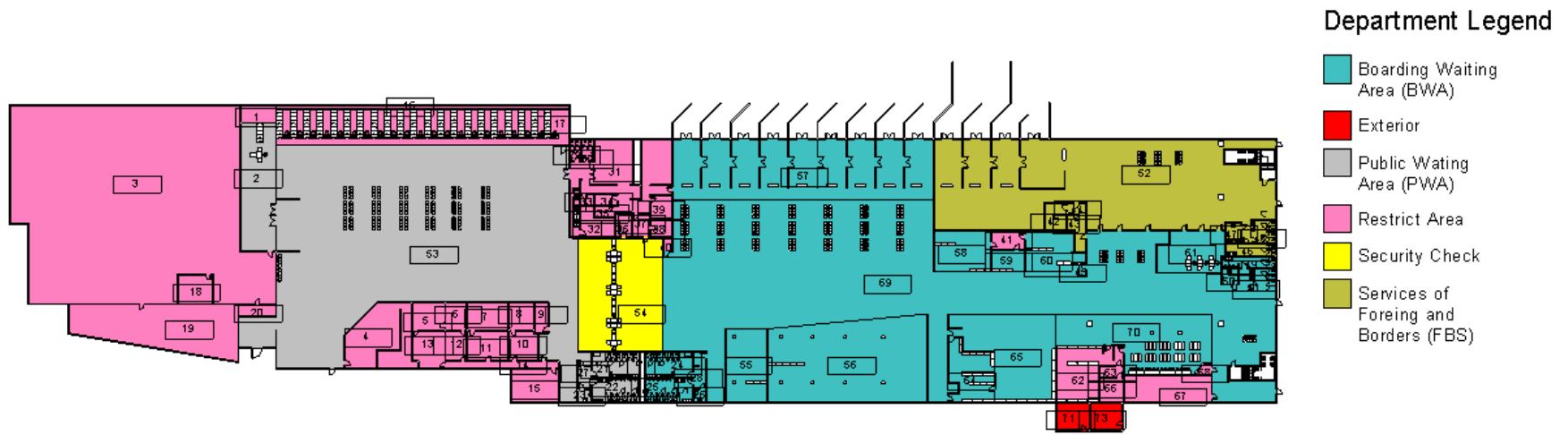


Figure 29: Terminal A Ground Floor Plan (Divided by Room Type)

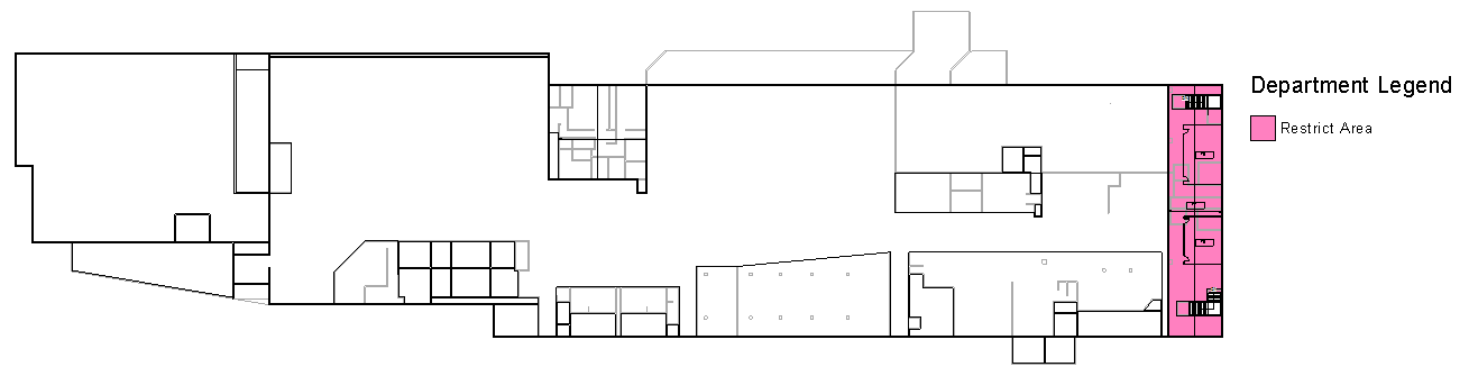


Figure 30: Terminal A First Floor Plan (Divided by Room Type)

## 4.3 Simulations in *Pathfinder*

### 4.3.1 Terminal A General Simulation Parameters

In the following group of simulations, some characteristics remain equal:

- **The profile, the location and the distribution of the occupants;**
- **The characteristics of the stairs and the exits of the building;**
- **The type of incident and its characteristics:** it is assumed that the simulated emergency situation in all scenarios is a spontaneous incident where there are no injured occupants or casualties, there is no alteration of the building due to the incident (there are no destroyed areas that prevent the evacuation of the occupants) and that all occupants immediately recognize the incident and automatically start their egress from the building;
- **The emergency signage assumptions:** in the simulations no information about Terminal A signage was introduced. However, there are doors that are locked or open only in one direction. There are also simulations where door restrictions (specific behaviors) and evacuation routes have been implemented, presupposing the existence of specific signs and that the occupants recognize this signage and comply unconditionally with it. However, from the modeling point of view this action is assumed, by default, as a characteristic behavioral rule of each occupant;
- **The airport infrastructure specific evacuation behaviors:** it is assumed that due to security issues related with the normal operation of airport infrastructures, the evacuation through the gates (from the interior of the building to the air side exterior platform), the movement of occupants through the security check-point and through the boarding area to the foreign and borders services area, are strictly prohibited.

Some of these simulations parameters are specified in the following topics. All the specific data about these modeling parameters features are provided in Annex 5.

#### Occupants Distribution and Location

As mentioned before, it is rare that airport terminals operate with its maximum capacity. The Terminal 2 of Lisbon Airport (Portela Airport, in Portugal), for example, usually only operates with 60% of its maximum occupancy (TAP, 2007). In Chapter 2, the regulations advised that designers should have in mind the total effective (maximum occupancy) when they plan the evacuation procedures and when entities execute a drill. Therefore, even airports rarely operate with the maximum capacity, it was decided that this type of simulation should be modeled for the maximum occupancy of the building, that is, all simulations were modeled with 2.500 occupants (representing 100% of the maximum capacity).

To calculate the distribution of the several profiles, it was necessary to use some literature references. The first one was used to estimate the number of passengers and the number of staff inside Terminal A.

Terminal 2 of Lisbon Airport has a total (occupable) area of 7.000 m<sup>2</sup> and it is known that it can operate with a maximum of 1.500 passengers (including PRM), (TAP, 2007). It is also known that Terminal A has a structure very similar to Terminal 2 (Lisbon Airport) and that has a total (occupable) area of 8.773,333 m<sup>2</sup>.

Therefore, as shown in Table 20, it is possible (making a correlation with Lisbon Terminal 2) to establish the number of passengers in Terminal A and (subtracting this value to the maximum occupancy of Terminal A, 2.500 occupants) the number of staff occupants inside Terminal A (as shown in Table 21).

Table 20: Calculation of the Maximum Number of Passengers (PRM Included) in Terminal A

Airport Terminal	Occupable Area [m <sup>2</sup> ]	Maximum Number of Passengers (including PRM)
Terminal 2 (Lisbon Airport)	7.000	1500
Terminal A	8.773,333	1880

Table 21: Calculation of the Number of "Staff" Occupants in Terminal A

Profiles		
Terminal A Maximum Occupancy	Passengers (PRM included)	"staff"
2.500 Occupants	1.880	620

In addition to the "staff" and "default" profiles, the objective was to study profiles of disabled occupants. As *Pathfinder* considers only the physical characteristics (dimensions, speed and location in space) of the occupants and since no type of emergency alarm is simulated it was decided to exclude occupants with cognitive, visual and auditory difficulties from the PRM group studied in the simulations. Thus, occupants using various types of devices to aid their locomotion were introduced into the PMR group. Although according to the current legislation occupants older than 65 years are seen as PMR, it was decided to separate this group from the PMR one since in their configuration in the simulations they do not use any type of auxiliary locomotion device.

The World Health Organization (WHO) reported that 12,0 % of the world population, in 2015, was above 65 years old and that 15,0 % of the world population, for the same year, had some

kind of disability (WHO, 2015a, 2015b). According to the Organization for Economic Co-operation and Development (OECD), in 2013 18,37 % of the European Union (28 countries) population and 14,15 % of the US population were above 65 years and 14 (OECD, 2013).

Although these references provide more realistic data for a European reality they do not specify the number of people by their mobility impairment. Thus, another reference was used to calculate the elder and the different PRM profiles distribution inside Terminal A. The US Department of Commerce Census Bureau provide annual census about the US demography. In 1997, 267,665 million people were registered in the US. According to the records, of the total American population (US Department of Commerce, 1997):

- 32,064 million of these people represented the age group of the population over 65;
- 8,527 million people had disabilities and used a type of locomotion aid. Within this group it was still known that 2,155 million people were wheelchair users and that 6,372 million people used crutches, rollators/hikers or walking sticks/canes.

Table 22 shows the equivalent percentages of these numbers.

Table 22: Mobility Types Distribution (Percentage) ((US Department of Commerce, 1997)

Profile	Registered Number of People in USA [million people]	Equivalent Percentage [%]
Total Population	267,665	100
Above 65 Years (“elder”)	32,064	11,979
Wheelchair	2,155	0,805
Crutches, Rollator/Hiker and Walking Stick/Cane	6,372	2,381
Without Mobility Impairments (Non-PRM)	227,074	84,835

Assuming these statistics and applying them to the distribution of profiles in Terminal A we were able to establish the number of occupants assigned with an “elder” and a PRM (“wheelchair”, “crutches”, “hiker” or “cane”) profile (Table 23).

Table 23: Calculation of Number of Occupants in Terminal A by Mobility Types

Terminal A Profiles	Percentage [%]	Number of Occupants [occupants]	Assumed Number for Simulation Modeling [occupants]
Maximum Occupancy	100	2.500	2.500
Above 65 Years ("elder")	11,979	299,5	300
Wheelchair	0,805	20,1	20
Crutches, Rollator/Hiker and Walking Stick/Cane	2,381	59,5	60
Without Mobility Impairments (Non-PRM)	84,835	2120,9	2120

For the profiles "crutches", "hiker" or "cane", because no specific data were known it was decided to make an equal distribution of this profiles in Terminal A (as shown in Table 24).

Table 24: Distribution of "Crutches", "Hiker" and "Cane" Profiles in Terminal A

Profile	Assumed Number for Simulation Modeling [occupants]	Percentage [%]
Crutches	20	
Rollator/Hiker	20	2,381
Walking Stick/Cane	20	
Total	60	

Therefore, the assumed distribution of occupants in the building for all the simulations is presented in Table 25.

Table 25: Profiles Distribution in Terminal A

Profile	Value Assumed for Simulations	
	n° of Occupants	%
> 65 Years	300	11,979
Wheelchair	20	0,805
Crutches	20	
Rollator/Hiker	20	2,381
Walking Stick/Cane	20	
Non-PRM Occupants	Default	1.500
	Staff	620
Total	2.500	100,0

As concluded in Chapter 3, the initial position of each occupant inside an infrastructure influences the results obtained in *Pathfinder* simulations, so it was established that the position for each occupant was the same in every simulation. This parameter was possible to establish using some Pathfinder specific tools.

### Occupants' Profile Characteristics

The occupants are represented in *Pathfinder* by cylinders/polygons/3D models. The cylinders and the polygons are represented by different colors to easily identify each type of occupant in the simulation results (in the video). Thus, the black cylinders represent the “*staff*”, the white cylinders represent the passengers without reduced mobility (“*default*” occupants), the grey cylinders represent the “*elder*” passengers and the pink cylinders and the pink parallelepiped represent the passengers with reduced mobility. The occupants have the profile features represented in Figure 31 and Figure 32.

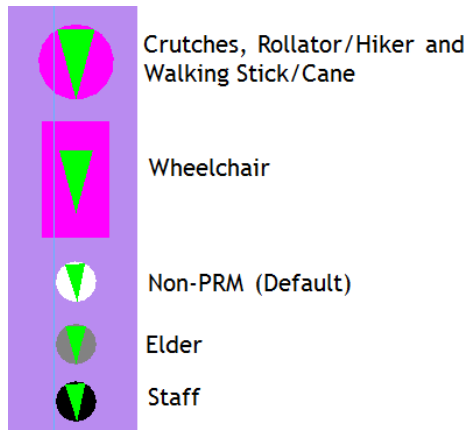


Figure 31: Terminal A Occupants *Pathfinder* Label

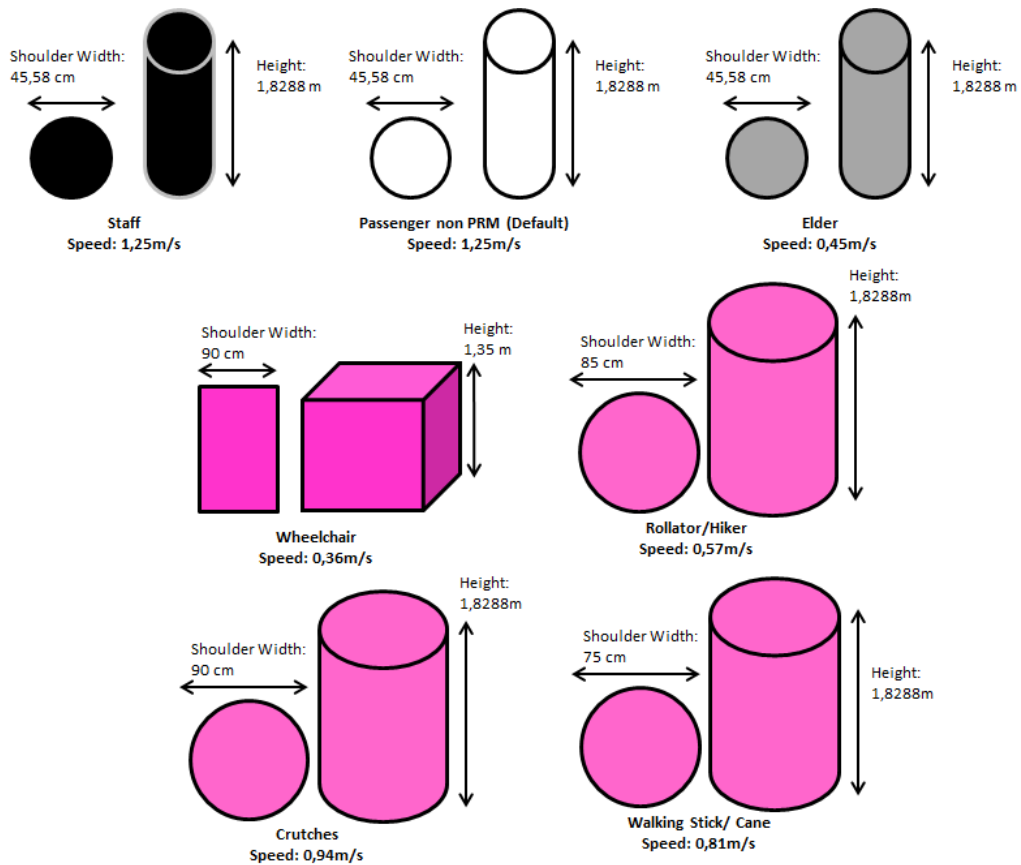


Figure 32: Characteristics of Terminal A Occupants' Profiles

It is important to refer that *Pathfinder* does not distinguish occupants' gender and that occupants are assumed as self-sufficient in their evacuation from the building. However, in the seventh simulation, the PRM passengers wait for assistance. This occurs in order to understand differences between evacuation strategies with or without need of assistance.

Despite the *Pathfinder* 2017 groups' recognition ability, it is assumed that it doesn't exist for all simulations (all occupants behave like individuals). However, in the seventh simulation,

the PRM occupants wait for assistance and then the PRM and the related assistant move like if they were a group itself.

**Exits and Stairs of Terminal A**

Terminal A has nine types of doors divided in exit doors (allowing the occupants to exit the building) and interior doors (allowing the occupants to move between rooms/areas inside the building). The exit doors are always open and the emergency doors are one-way doors (only allowing the exit of occupants). The interior doors are always open except the gate communication doors, the gate doors (because airports rarely evacuate passengers from the terminal to the exterior boarding platform), boarding waiting area (BWA) to foreign and borders services (FBS) doors (BWA to FBS door), and some restrict doors that close in case of emergency 1 second after the emergency detection/alarm ( $t=1s$ , the door closes). Figures 33 and 34 show the doors' characteristics.

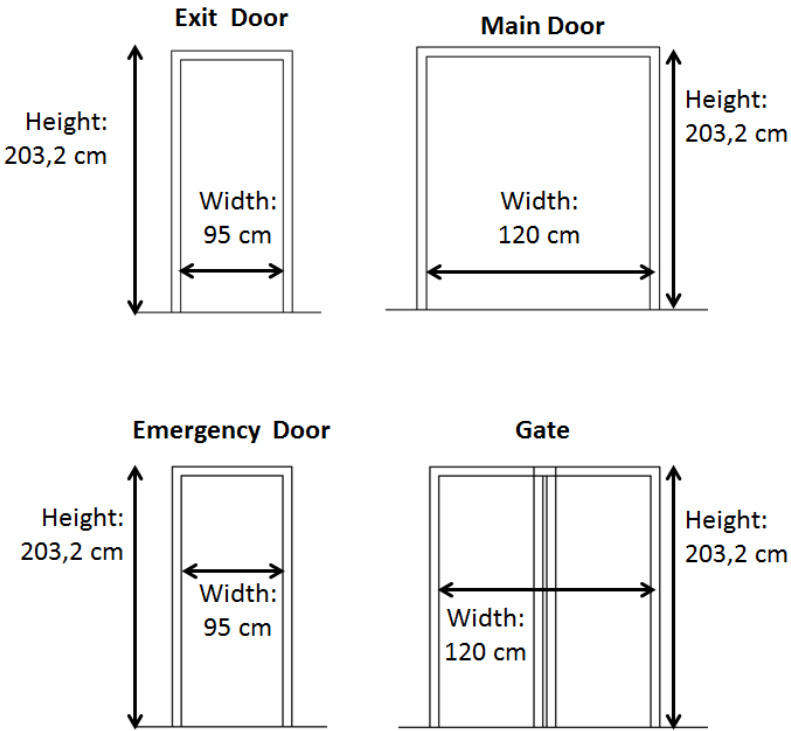


Figure 33: Terminal A Exit Doors Characteristics

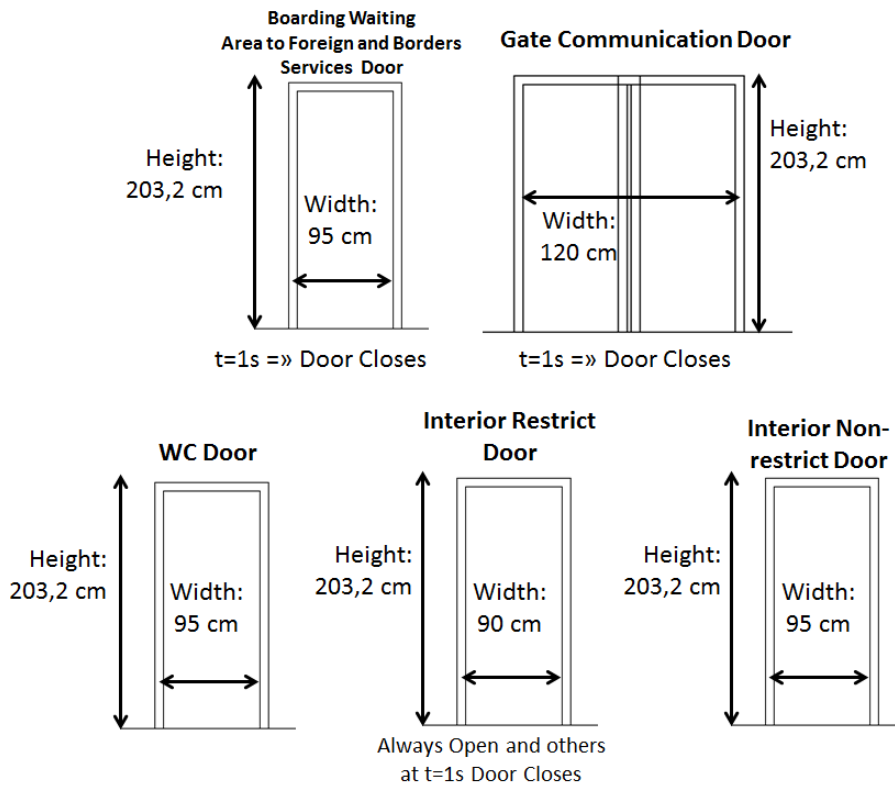


Figure 34: Terminal A Interior Doors Characteristics

There are two stairs in the building that were named “Stair1” and “Stair2”. These stairs are composed by 4 pieces and allow only staff to ascend to the first floor. In Figures 35, 36 and 37, represent these stairs characteristics.

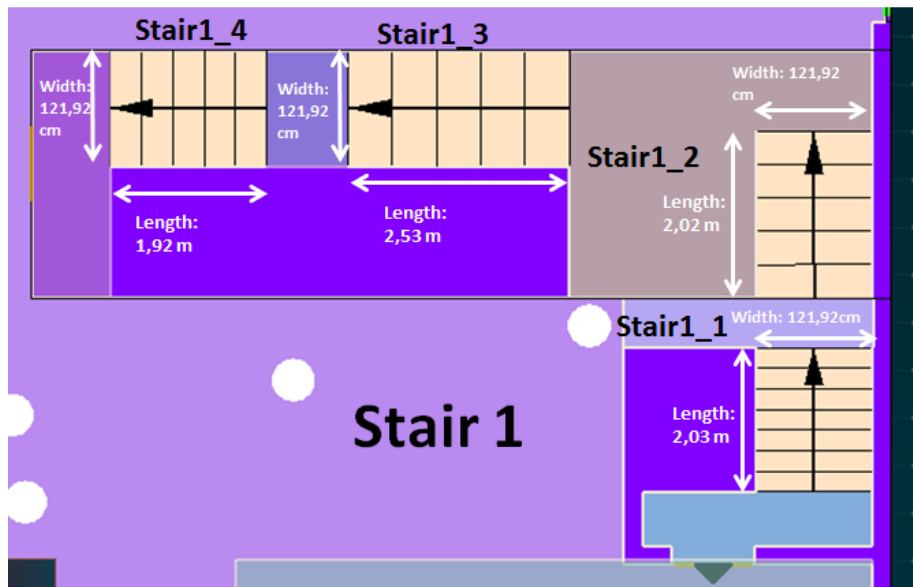


Figure 35: Terminal A Stair1 Characteristics

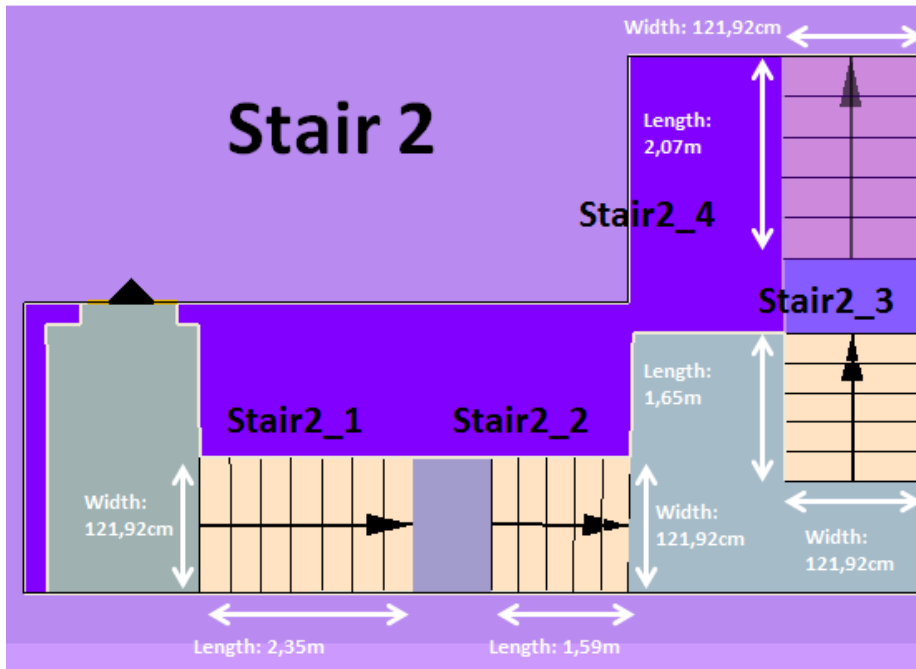


Figure 36: Terminal A Stair2 Characteristics

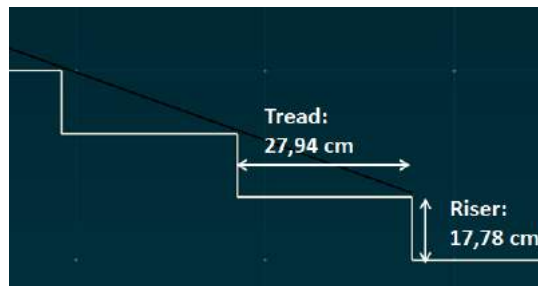


Figure 37: Terminal A Stair1 and Stair2 Characteristics

In Annex 5 is presented a summary of the modeling parameters described above for each simulation.

#### 4.3.2 First Simulation-Original Geometry

To understand the difference between the evacuation of a building with and without PRM and elder passengers, this first simulation is sub-divided in two scenarios: Sim 1 (with PRM and elder) and Sim 1A (without PRM and elder). However, in both simulations the general parameters and geometry were used with the implementation of a behavior that makes the occupants choose the fastest exit path selecting the closest exit door. The flowchart in Figure 38 represents this behavior. Figure 39 indicates the exit doors location in Terminal A. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

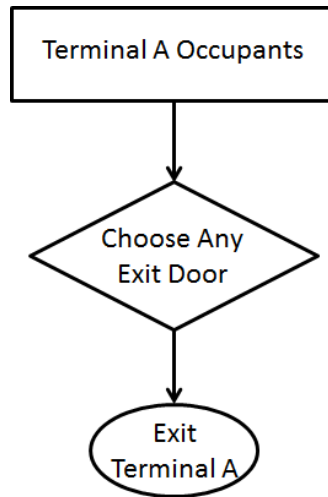


Figure 38: First Simulation (Sim 1 and Sim 1A) Occupants' Behavior

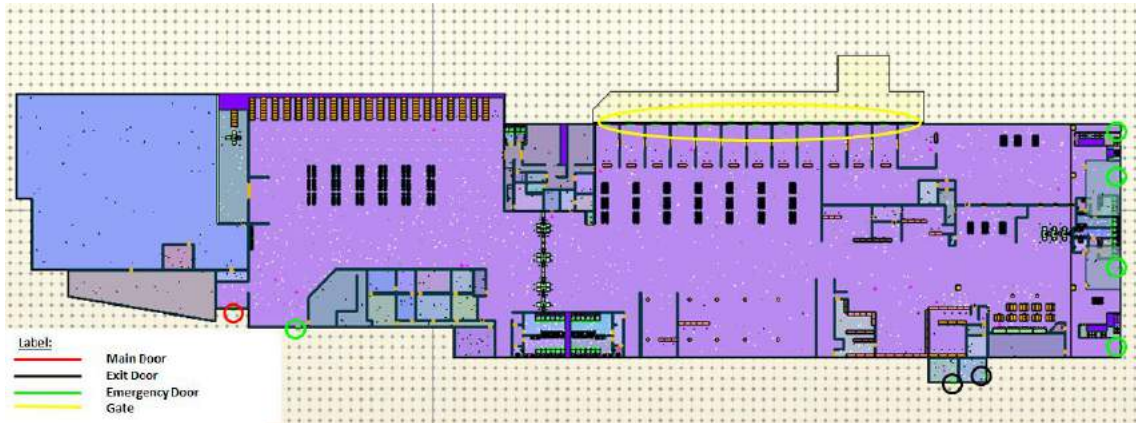


Figure 39: First Simulation (Sim 1 and Sim 1A) Geometry and Exit Doors Location

#### 4.3.3 Second Simulation

In this simulation three strategies were adopted. Decision making was implemented with several behaviors obligating occupants to choose the closest door in their placement area. This route/path creation will avoid some doors congestion.

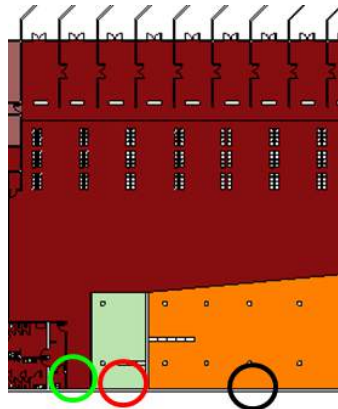


Figure 40: Second Simulation Occupants' Exit Choice Example

In Figure 40, for example, the occupants located in the Boarding and Waiting Area (BWA), represented as the *bordeaux*-colored one, will only choose to exit through the door signed with the green circle. The occupants located in the orange area will only exit through the door signed with the black circle and the occupants in the light green area will only exit through the door signed with the red circle. Thus each group only will leave the respective zone using the respective exit. In Figures 41 and 42, the colors represent the division of exiting areas and the passengers located in these areas are the respective exit groups.

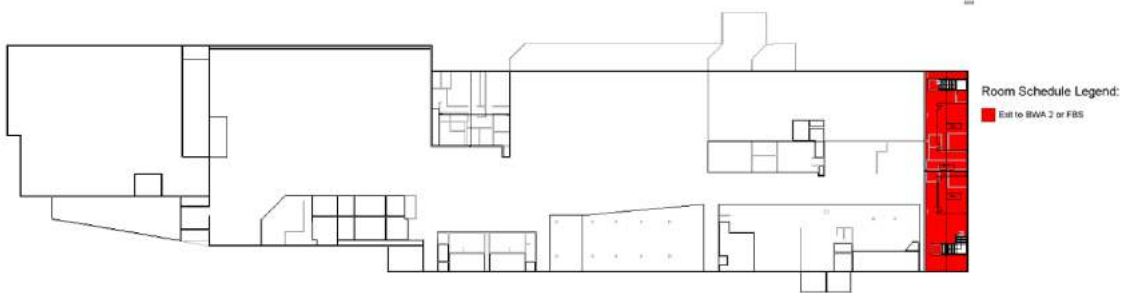


Figure 41: Terminal A Second Simulation Exit Groups (First Floor)

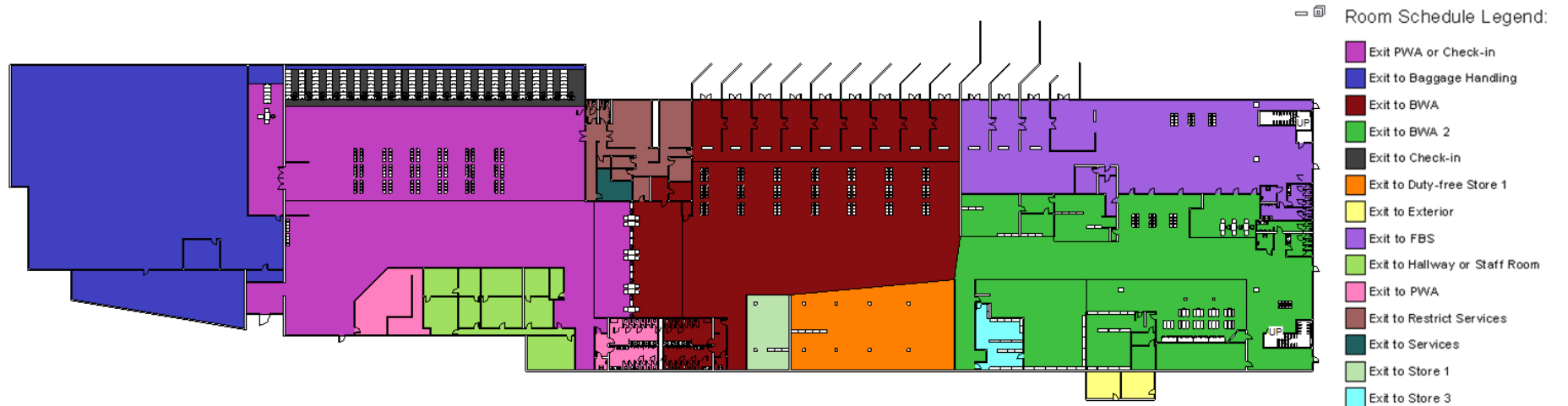


Figure 42: Terminal A Second Simulation Exit Groups (Ground Floor)

According to Figures 41 and 42, the flowchart of Figure 43 represents the occupants' behavior.

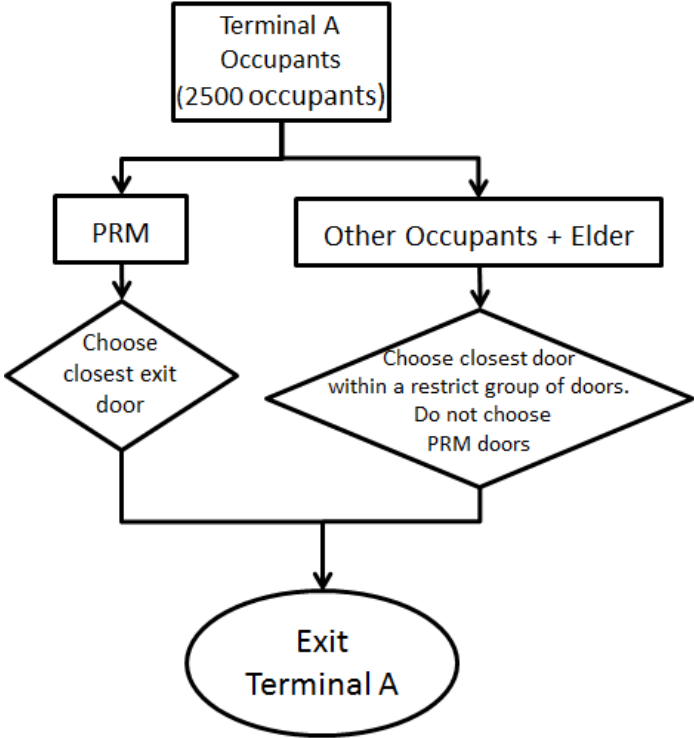


Figure 43: Second Simulation Occupants' Behavior

Exit doors in strategic places/rooms were added to the original geometry to allow some groups of occupants to exit faster and. It is assumed that a physical division exists on the exterior of the Terminal A that prevents occupants that exit through the doors near the check-in counters and through the baggage and services restrict rooms to enter in the air side platform. Also, to complement the addition of emergency doors it was decided to test the elimination of some unnecessary walls and the suppression of a check-in counter. In Figure 44 the new geometry of Terminal A and the location of its exits are presented. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided

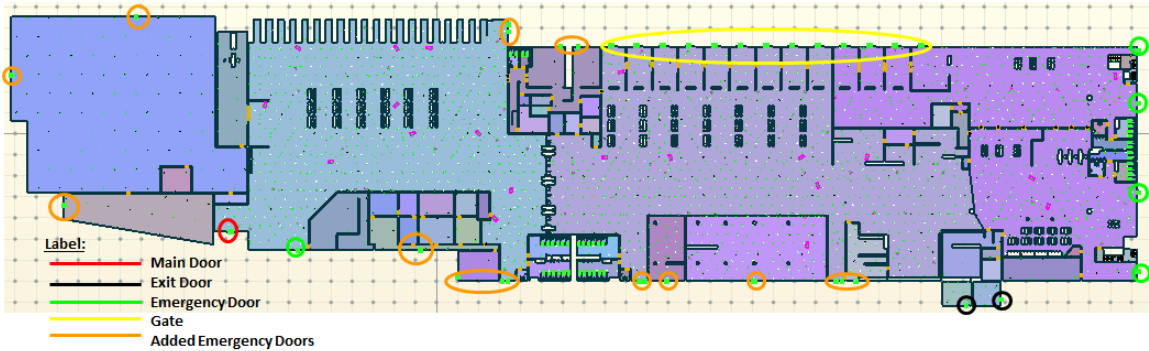


Figure 44: Second Simulation Geometry and Exit Doors Location

#### 4.3.4 Third Simulation

In this scenario some priority emergency doors for PRM (“PRM\_ED”) were added to the second simulation exits (Figure 45). These doors will allow PRM to exit the building faster with the creation of a behavior that allows PRM to use these doors and forbid other occupants to use them. In this simulation elder occupants are not allowed to use these PRM exit doors. This behavior is represented in the flowchart of Figure 46 and all the location of all the exit doors existent in this simulation is indicated in Figure 47. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

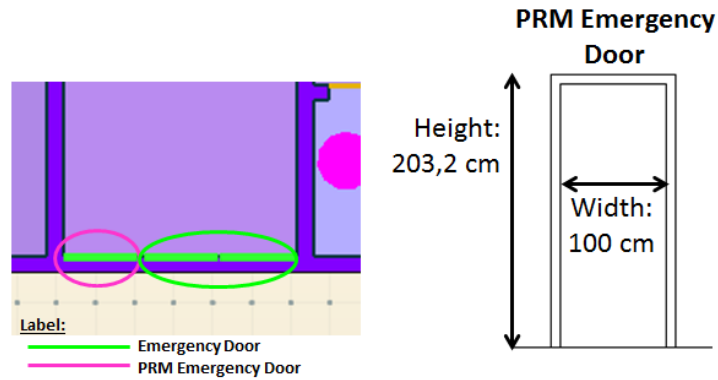


Figure 45: PRM Emergency Door Characteristics

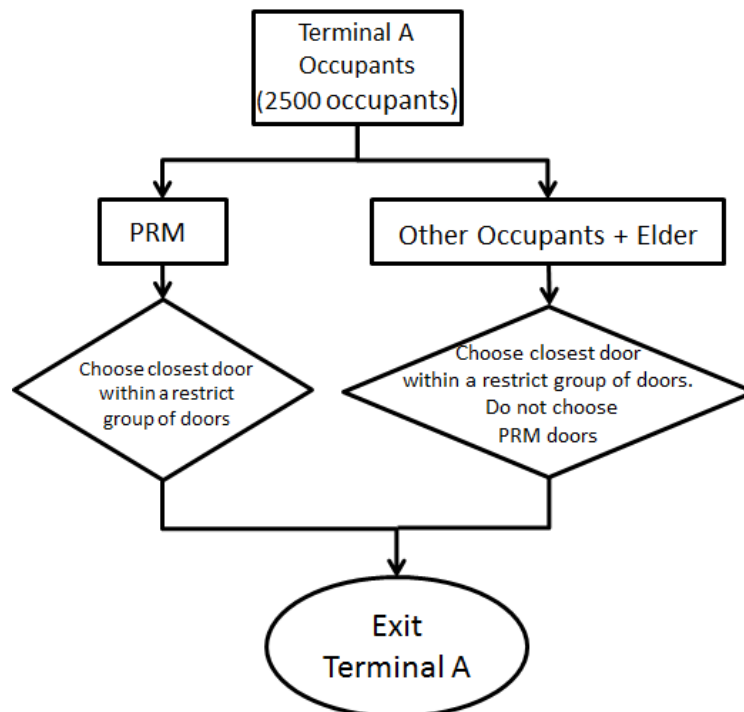


Figure 46: Third Simulation Occupants' Behavior

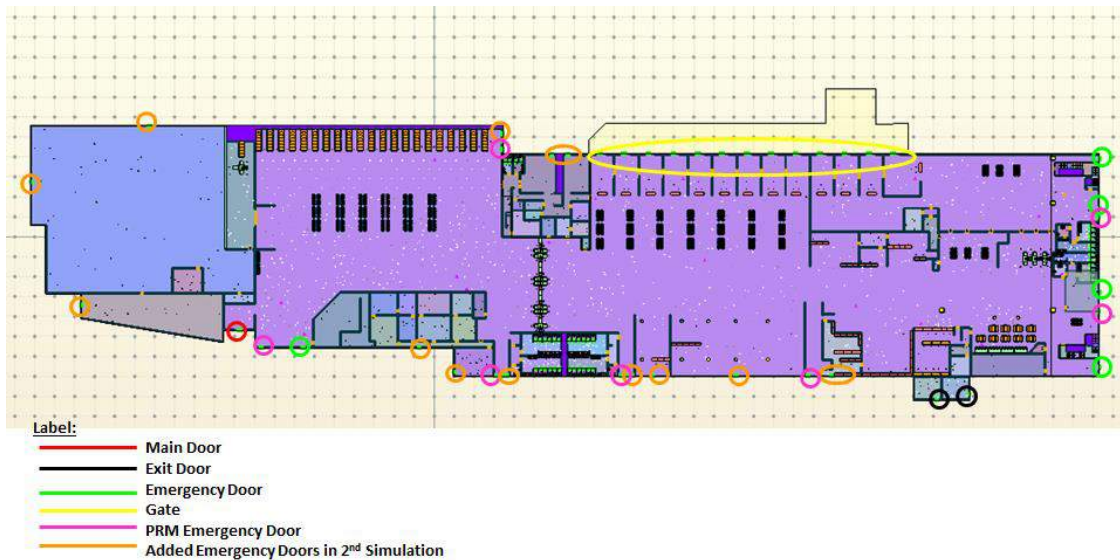


Figure 47: Third Simulation Geometry and Exit Doors Location

#### 4.3.5 Fourth Simulation

In fourth simulation the occupants' behavior, the exit door location and the geometry of the Terminal are the same as in third simulation and the doors were maintained but a separation wall was placed beside the priority emergency doors to easily separate PRM from non-PRM and create a less dense path to exit both groups (Figure 48). In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

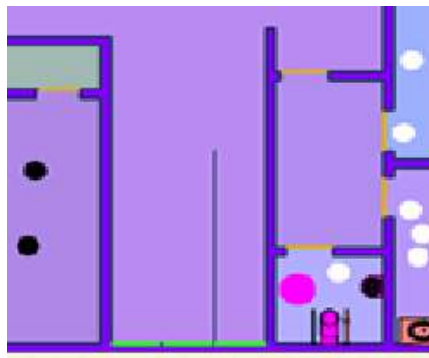


Figure 48: Separation Wall of PRM Emergency Door

#### 4.3.6 Fifth Simulation

In this scenario the impact of the evacuation of the first floor occupants through two exterior ramps (composed by four pieces each) was studied implying the addition of a new behavior implemented to the first floor occupants (Figure 49). Therefore, to the fourth simulation exits was added one emergency door.

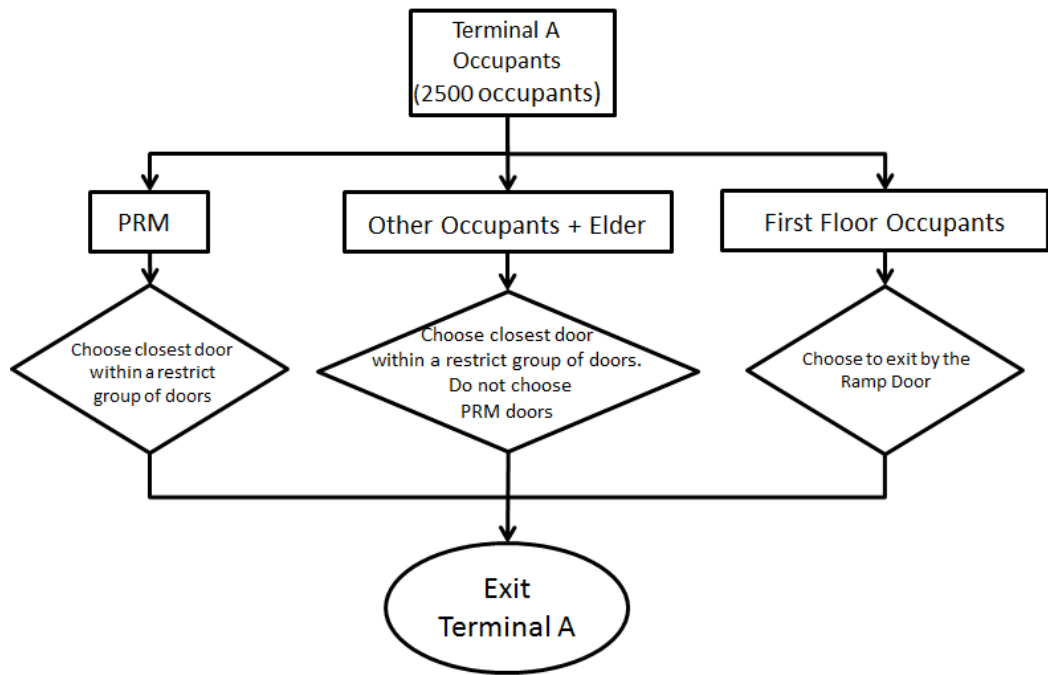


Figure 49: Fifth Simulation Occupants' Behavior

The two ramps (Figure 50) characteristics are represented in Figure 51. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

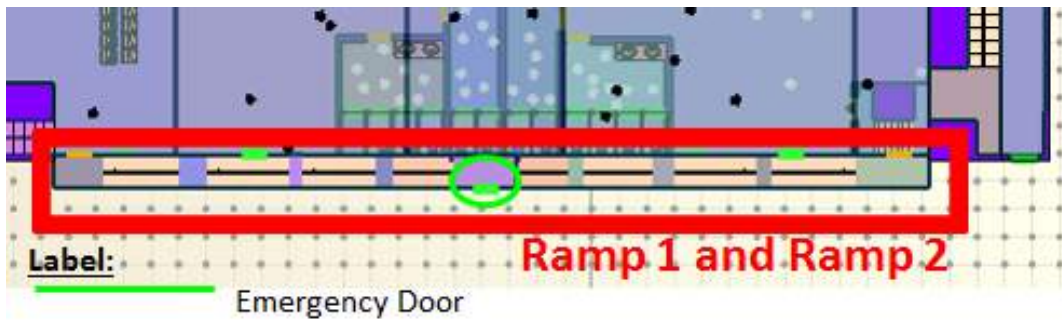


Figure 50: Terminal A Fifth Simulation Ramps Location

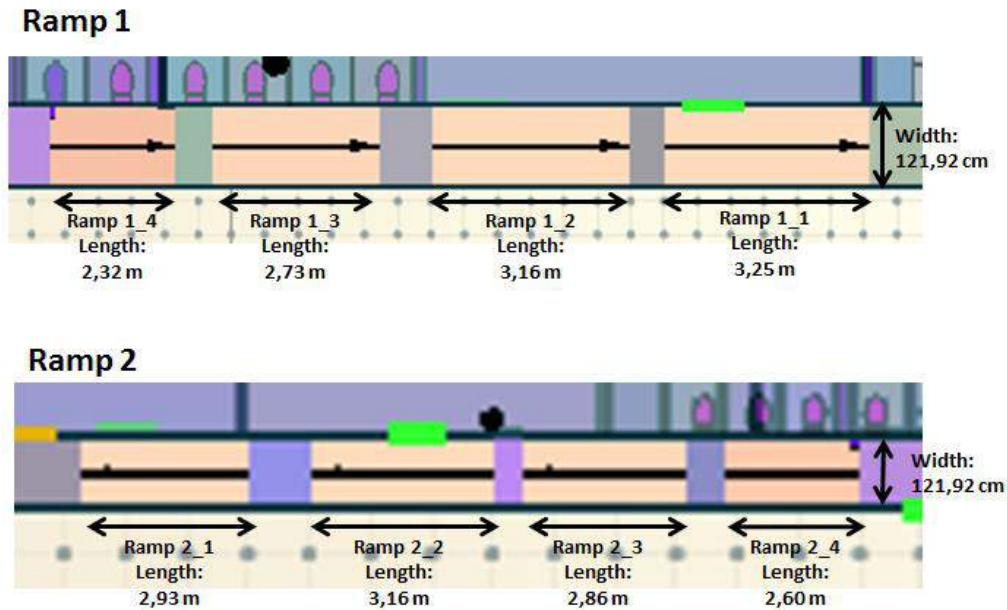


Figure 51: Fifth Simulation Ramp Characteristics

#### 4.3.7 Sixth Simulation

Since the 2017 version of *Pathfinder* was released in January, it was decided to take advantage of its new modeling features and run two more simulations. In this sixth simulation the objective was to test a less conventional evacuation strategy: the utilization of refuge areas. It is intended to change the behavior of the PMR occupants who instead of choosing an evacuation route leading them to an exit will choose an egress route that will lead them to the nearest refuge zone. In order for this strategy to be applied it is of course assumed that these types of zones are infrastructures built to withstand any incident (to assure its occupants safety and security) and that the PMRs are aware that they should address one of these zones and not an exit. Thus, the flowchart of Figure 52 represents the behavior applied to the occupants in this simulation. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

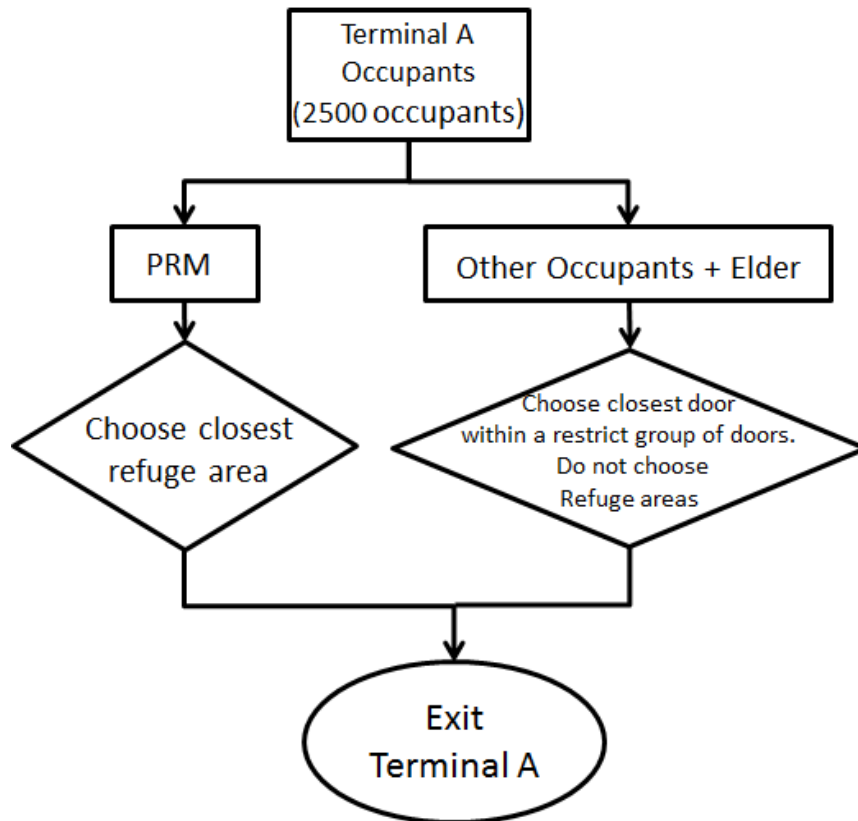


Figure 52: Sixth Simulation Occupants' Behavior

In this simulation, the priority doors were removed and the exit location and the geometry are the same as the second simulation. Figure 53 points (in red) the strategic location of these refuge areas.

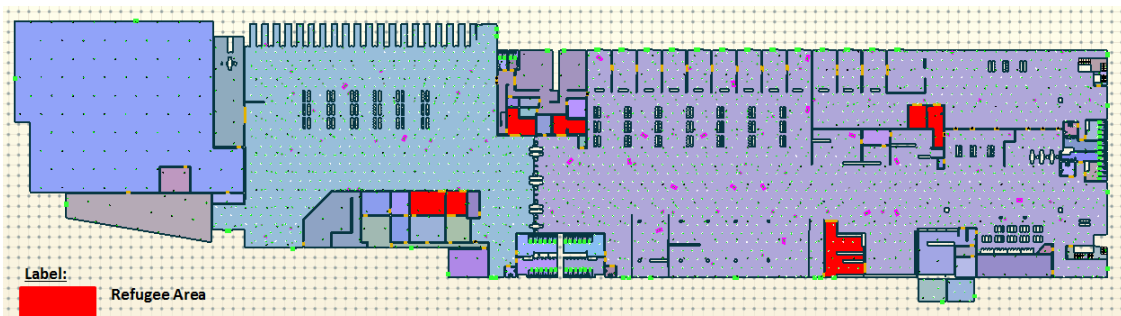


Figure 53: Sixth Simulation Geometry and Refuge Areas Location

#### 4.3.8 Seventh Simulation

The objective of this simulation was to test a new evacuation strategy resorting again to refuge areas, but this time using evacuation assistance teams. This way, the PRM occupants will again choose to go to a refuge area but will have to wait for an assistant to assist them in their travel. Therefore, it is necessary the addition of two new behaviors: a first one requiring the PMR occupant to wait for assistance and a second one requiring an occupant of the

evacuation crew (all “staff” occupants) to assist the occupants with reduced mobility in their movement to a safe area. Once inside a refuge area the assistant may assist other passengers or stay in it if no more assistance is need.

It is once again assumed that the PRM are aware that they have to wait and that the intervention teams are aware of whom they are obliged to provide assistance. Thus, the flowchart of Figure 54 represents the behavior applied to the occupants in this simulation and Figure 55 shows the strategic location of these assistance teams. The refuge areas are located in the same place as in sixth simulation. In Annex 5 and Annex 6 general and specific parameters of this simulation are provided.

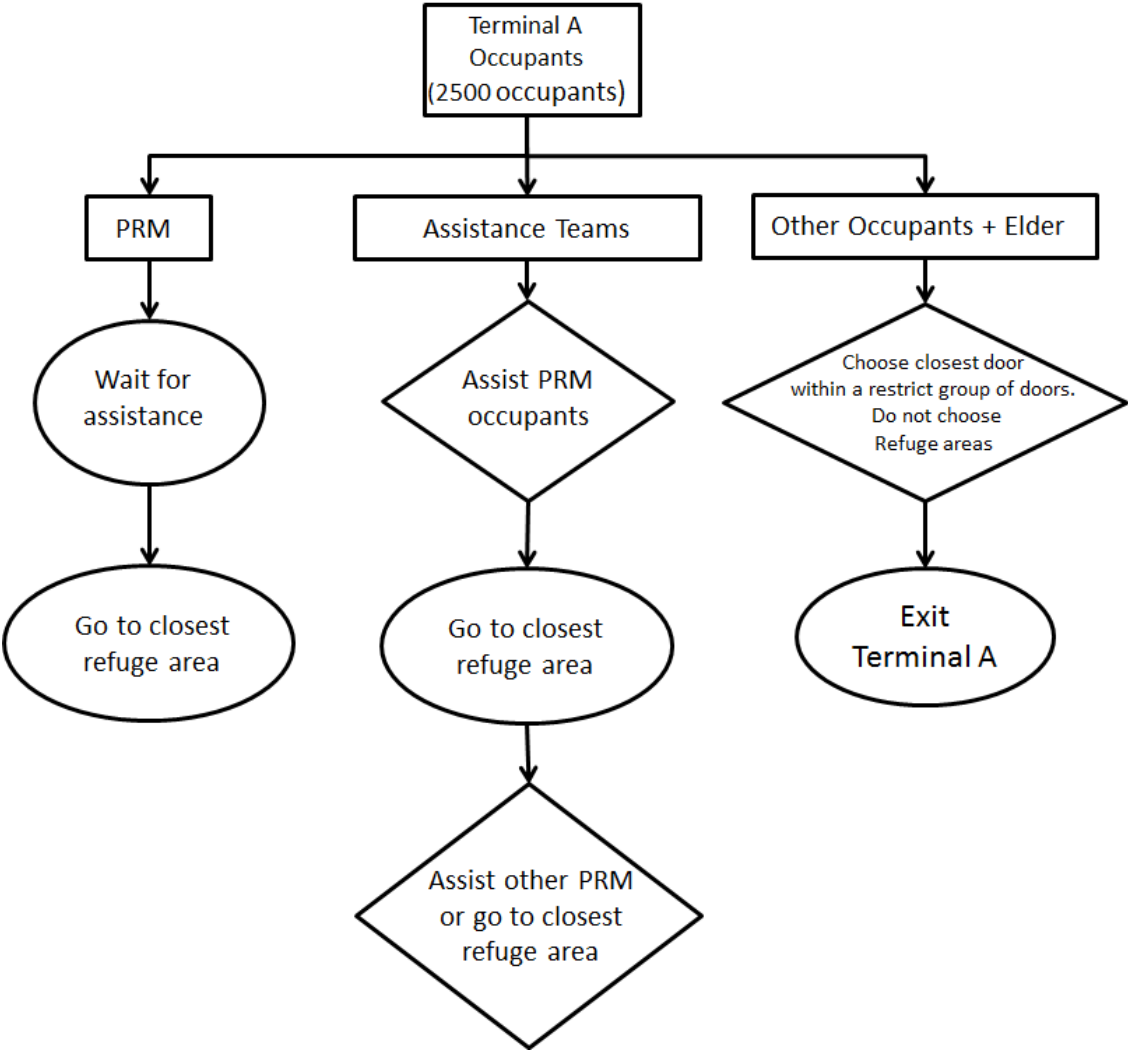


Figure 54: Seventh Simulation Occupants' Behavior



Figure 55: Seventh Simulation Geometry and Assistance Teams Location

By default, all PRM occupants are represented as polygons because it is the only possibility that an assistant can attach himself to an occupant.

#### 4.4 Pathfinder Simulation Results

To obtain results in the simulation tool all the scenarios mentioned in the previous section were loaded and tested in the designed geometry. To all the simulations two numerical values of time are obtained: the time of evacuation (that is the time to exit all occupants) and the time of simulation run (that tell us how long a simulation takes to generate results). These results for all simulations are presented in Table 26, where:

- $t_{run}$  = time of simulation run;
- $t_{evac}$  = time of evacuation.

Table 26: Case of Study Simulation Results (Time of Evacuation)

	1 <sup>st</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	6 <sup>th</sup>	7 <sup>th</sup>
	Simulation (1)	Simulation (1A)	Simulation	Simulation	Simulation	Simulation	Simulation	Simulation
	[s]	[s]	[s]	[s]	[s]	[s]	[s]	[s]
$t_{evac}$	733,3	568,8	191,3	184,3	198,3	201,8	226,3	274,5
$t_{run}$	715,4	738,1	240,2	234,3	302,7	273,0	229,6	306,5
								2500 Occupants

For each simulation were obtained graphics that show the exit doors flow rate variation in time divided in groups of exits: PWA exit doors (“MainDoor”, “ED1”, “ED6”, “ED9”, “ED10” and “ED11”), BWA exit doors (“ED7”, “ED8”, “ED12”, “ED13” and “EDstore3”) and the BWA2 and FBS exit doors (“ED2”, “ED3”, “ED4” and “ED5”).

For each door it is also known the time of the last occupant that exits through the door (time when the door is no longer used as an exit) and the number of occupants that used a door in all simulation time. A compilation of these measured values to each simulation is available in Annex 7 that allows the easy understanding of the doors flow rate differences. From all the simulations were also obtained videos with recordings of the simulations that allow the easily understanding of the occupants' movement, congested doors and the block between occupants, and an image of the occupants' egress route decision (available in Annex 8). These videos are available in the annexed CD, as previously mentioned.

**4.4.1 First Simulation**

The first simulation was made with the original geometry of the Terminal A and with 2.500 occupants. The parameters of geometry and profile and behavior of the occupants were the ones described in sections 4.3.1 and 4.3.2 of this chapter, and in Annexes 5 and 6. These data are the input of the simulation and from the data simulation run were obtained results that let to conclusions (output). The flowchart of Figure 56 sums up these inputs and outputs. It is important to remind that two scenarios are analyzed in this first simulation. The only difference between them is the profile of the occupants: in scenario 1A only the profile existent is a non-PRM profile.

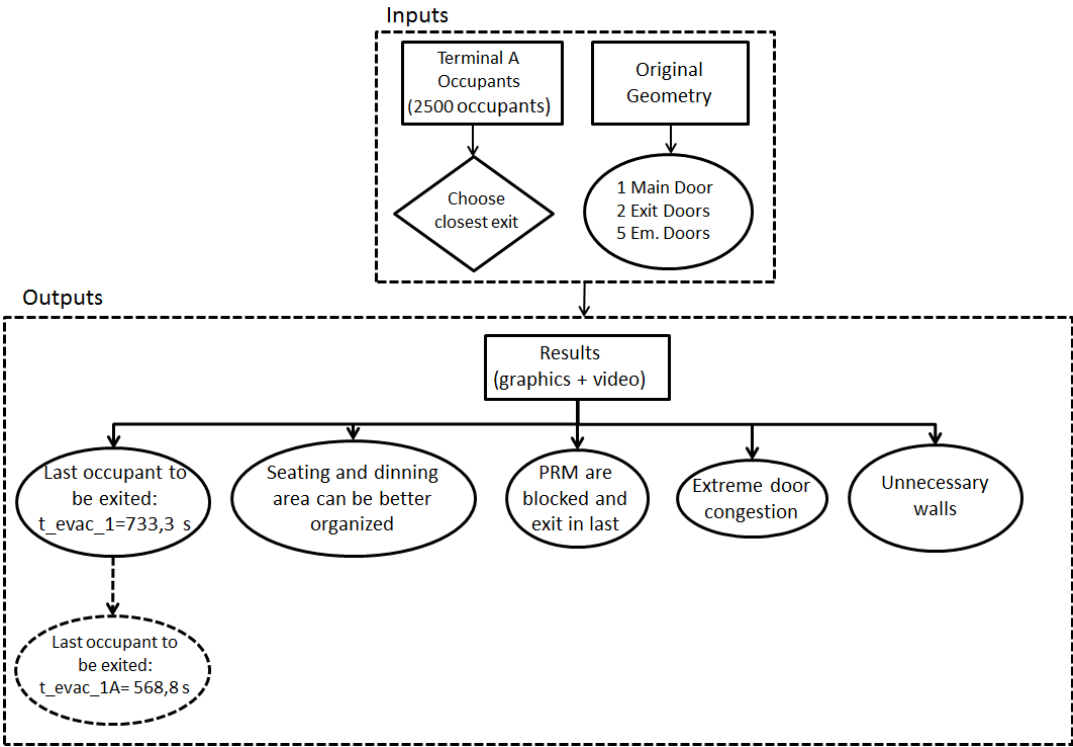


Figure 56: Terminal A First Simulation Results (Inputs and Outputs)

From the results we conclude that some identified problems can be solved by adding emergency doors in strategic places, with the change of sitting and dining areas configuration and with the removal of some unnecessary walls. Figures 57 to 60 proof the first simulation outputs/results.

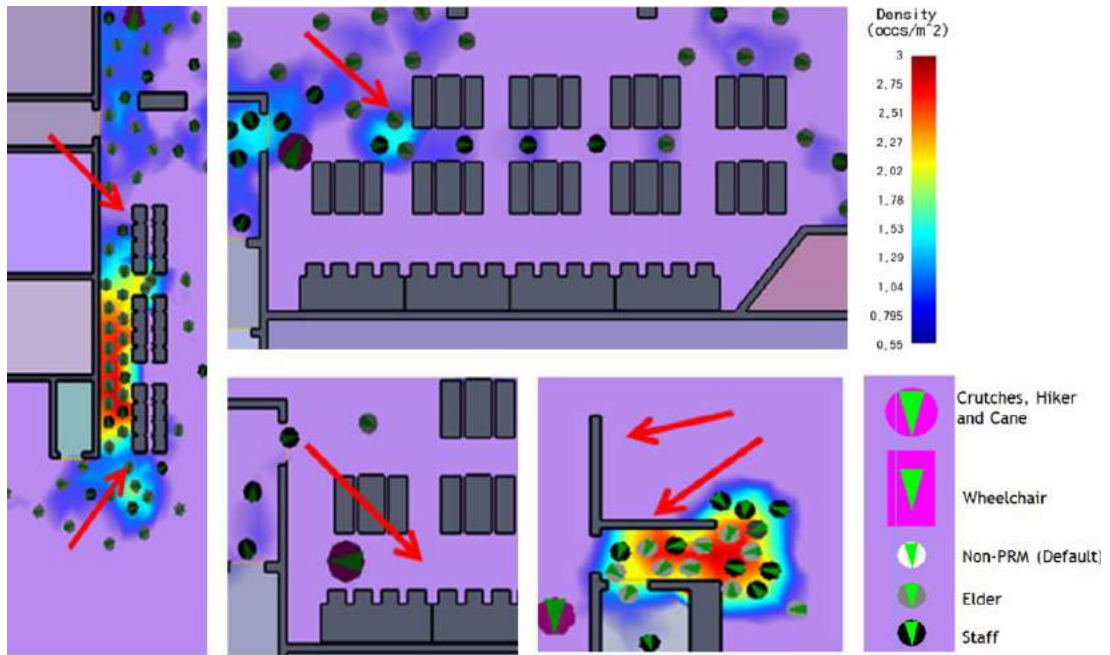


Figure 57: Bad Configuration of Dining/Seating Areas and Unnecessary Walls of Terminal A

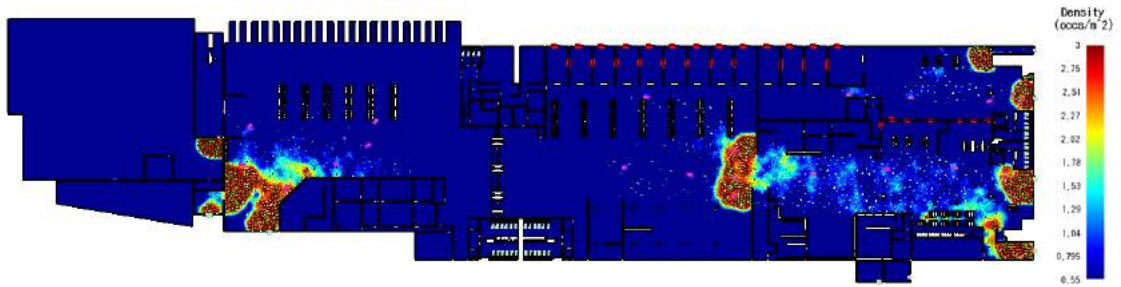


Figure 58: Simulation 1 Occupants' Density at t=50,0 s

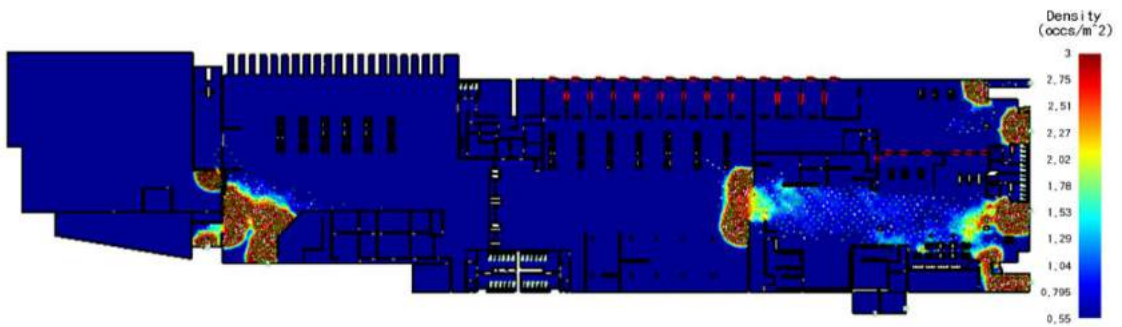


Figure 59: Simulation 1A Occupants' Density at t=50,0 s

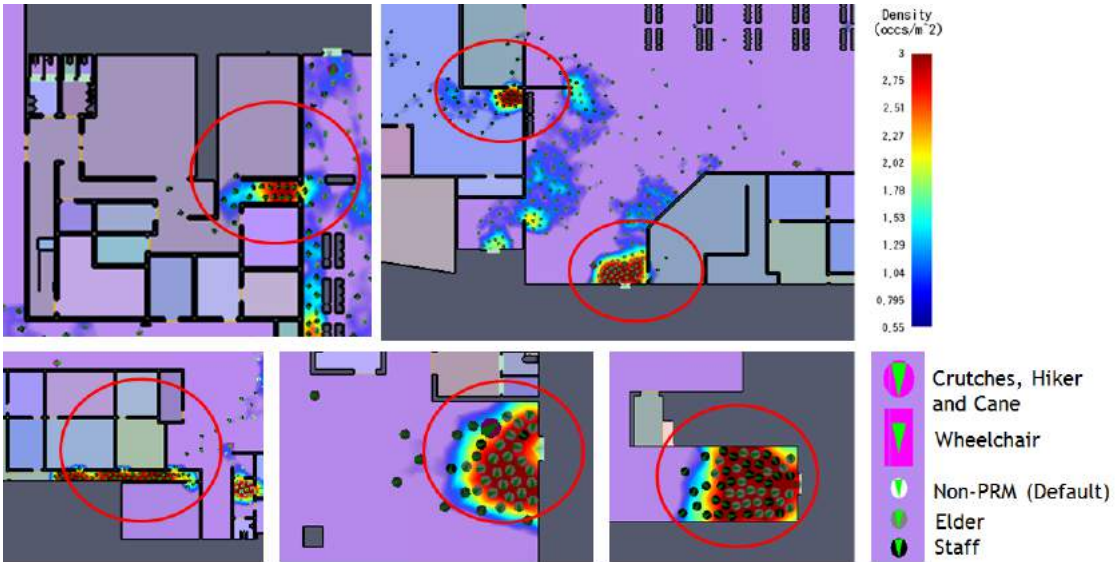


Figure 60: Door Congestion in Simulations 1 and 1A

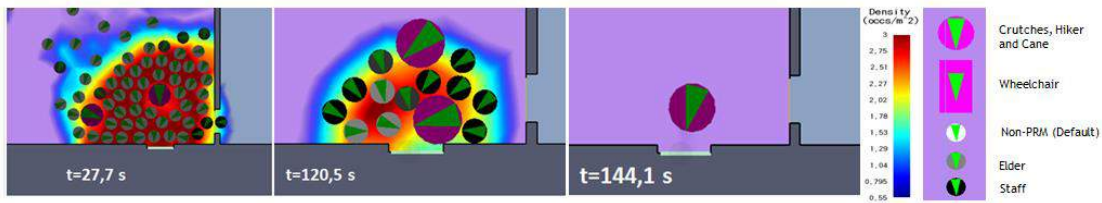
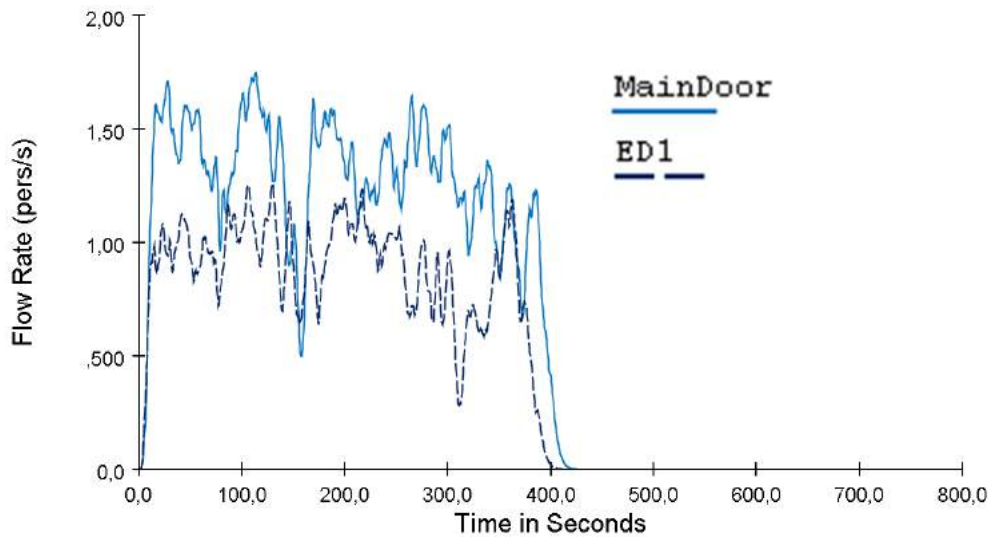
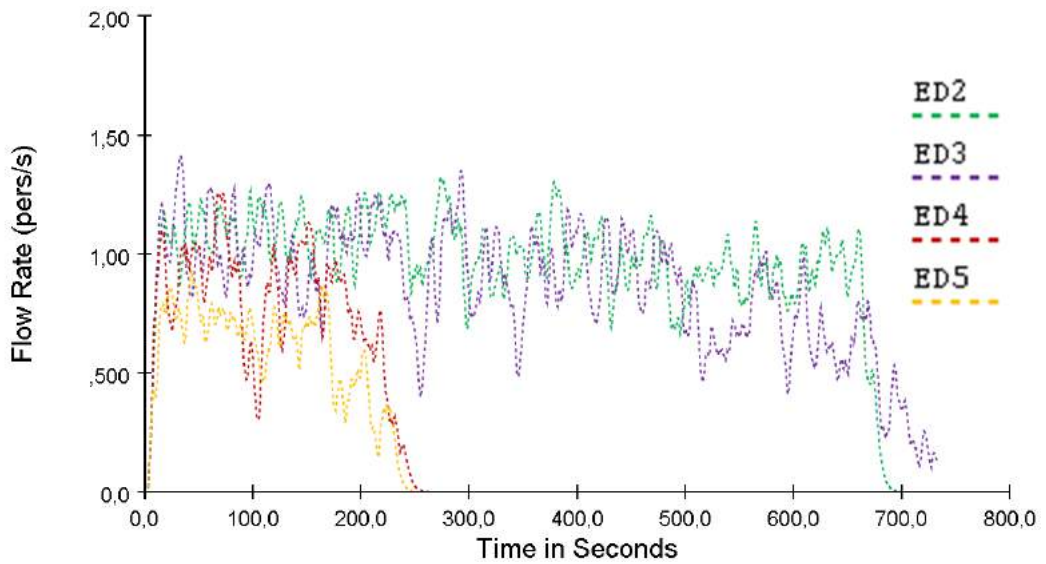


Figure 61: PRM Being Block by Other Occupants in Simulation 1

Graphic 1 and Graphic 2 represent the flow rate of the first simulation exits.



Graphic 1: PWA Flow Rate in Simulation 1



Graphic 2: BWA2 and FBS Flow Rate in Simulation 1

#### 4.4.2 Second Simulation

In the second simulation the inputs were the same occupants' profile and behavior used in first simulation and as well as the geometry, but now with the addition of 17 emergency doors at strategic locations and without some unnecessary walls and with the suppression of one check-in counter. In an attempt to decrease the flow rate in the exit doors the behaviors now restrung the exit door choice according to the occupants' location. These data are described in sections 4.3.1 to 4.3.3 of this chapter, and in Annexes 5 and 6. Figure 62 sums up the simulation inputs and outputs (results) and Figures 63 to 65 are proof of these results and of some observations.

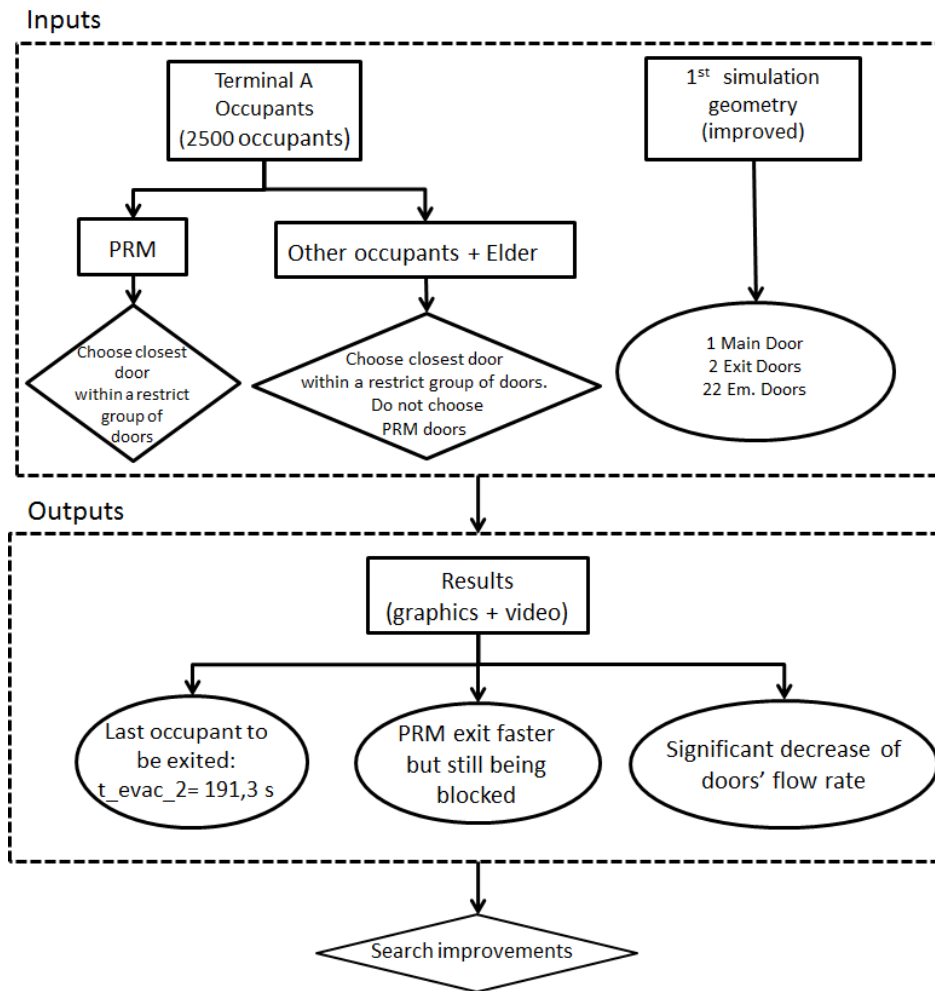


Figure 62: Terminal A Simulation 2 Results (Inputs and Outputs)

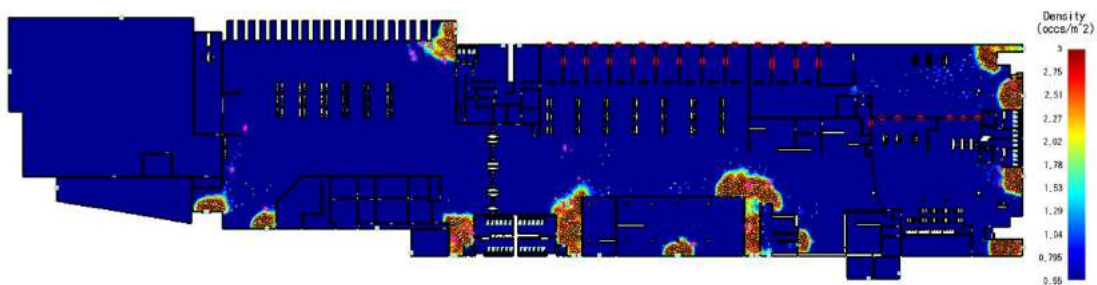


Figure 63: Simulation 2 occupants' Density at t=50,0 s

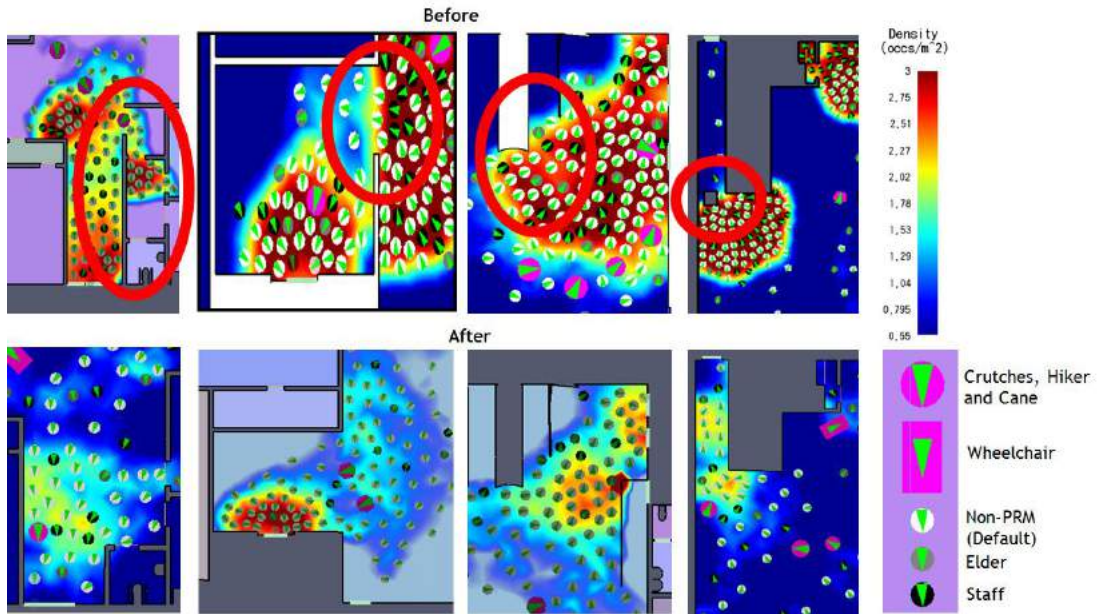


Figure 64: Some Configurational Alterations of Simulation 2 and its Impact in Density

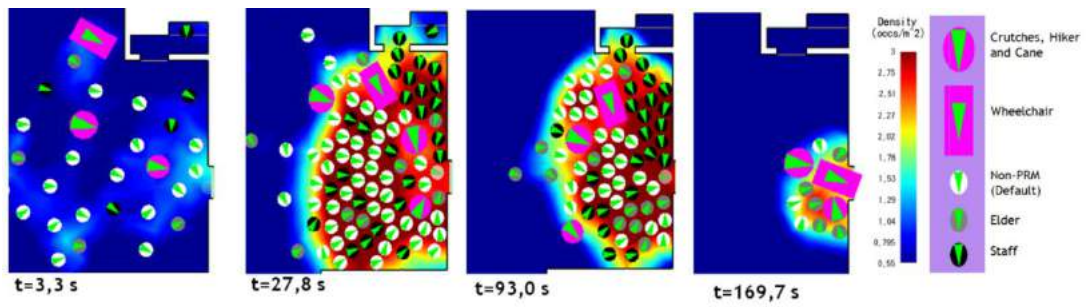
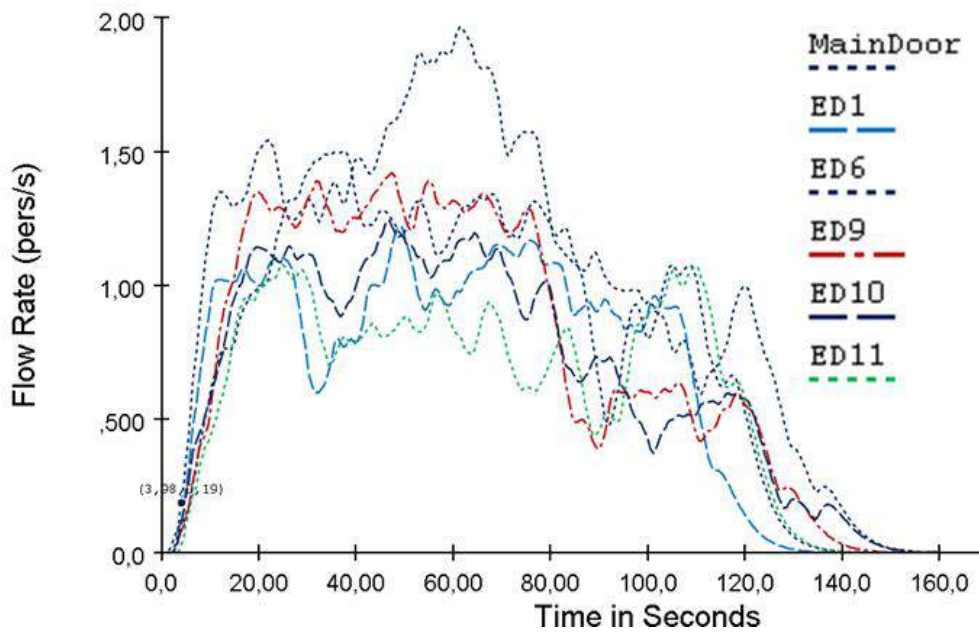
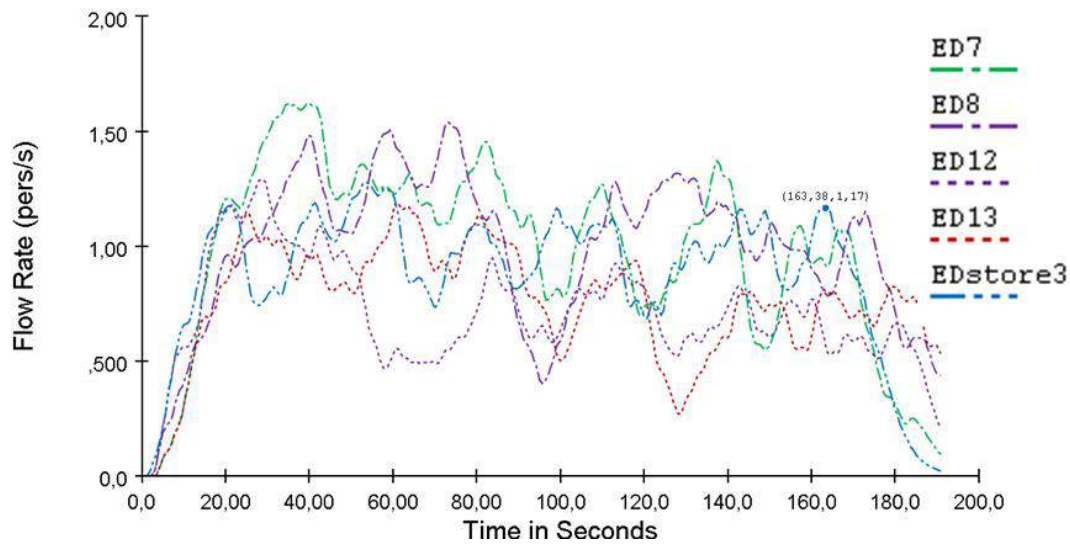


Figure 65: PRM Occupants Being Blocked by Other Occupants in Simulation 2

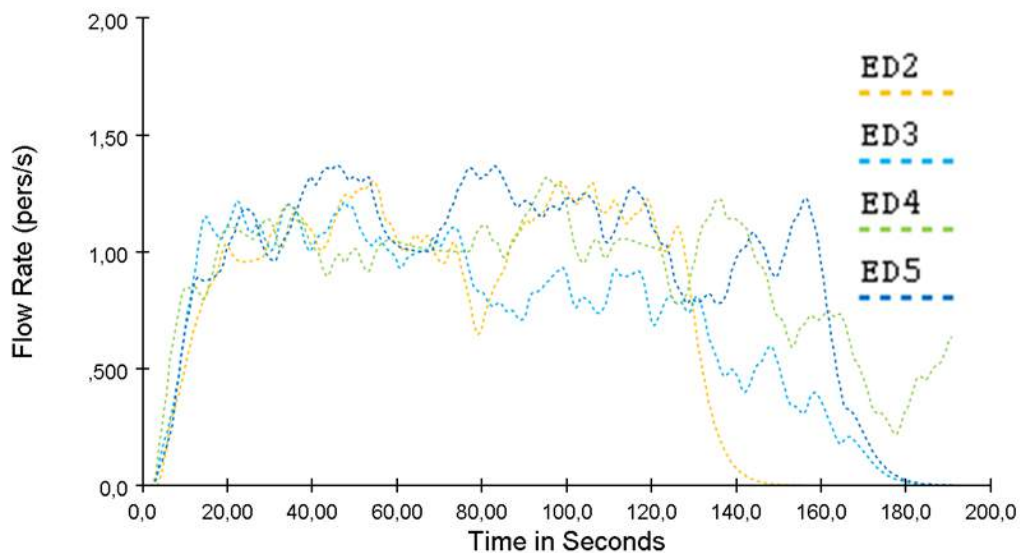
Graphics 3 to 5 represent the flow rate of the second simulation exits.



Graphic 3: PWA Exit Doors Flow Rate in Simulation 2



Graphic 4: BWA Exit Doors Flow Rate in Simulation 2



Graphic 5: BWA2 and FBS Exit Door Flow Rate in Simulation 2

#### 4.4.3 Third Simulation

In this simulation the inputs were the second simulation geometry with the addition of seven PRM emergency doors and the occupants of the first simulation with two behaviors that allow, or do not allow, PRM or other occupants to use the PRM emergency doors, respectively. In this scenario the elder occupants were not included in the PRM occupants, therefore, were not allowed to use the priority doors. These data are described in sections 4.3.1 to 4.3.4 of this chapter, and in Annexes 5 and 6. The flowchart in Figure 66 describes the results (inputs and outputs) of this simulation.

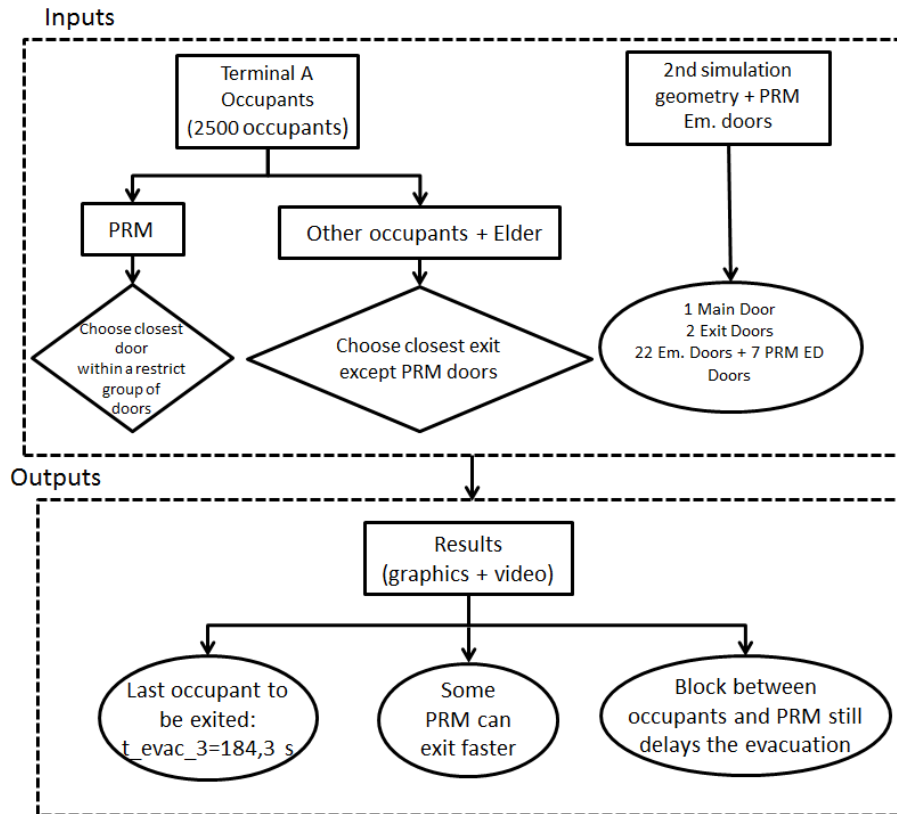


Figure 66: Terminal A Simulation 3 Results (Inputs and Outputs)

Figures 67 and 68 proof the third simulation results/outputs and Graphics 6, 7 and 8 represent the flow rate of the third simulation exits.

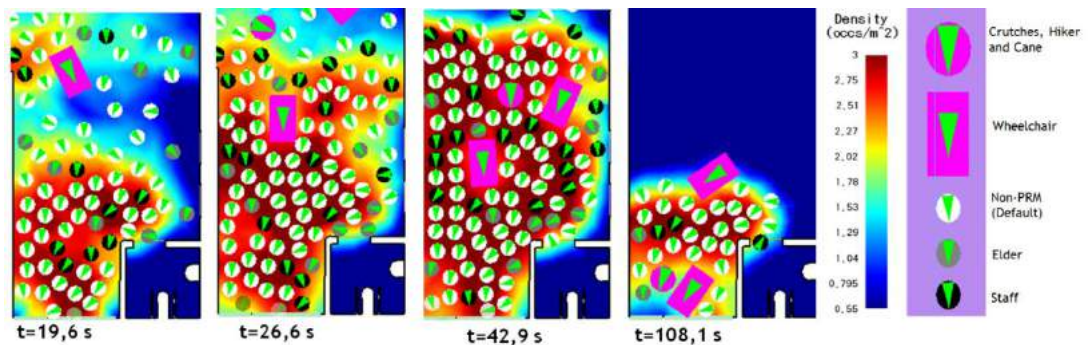


Figure 67: PRM Occupants Being Blocked in Simulation 3

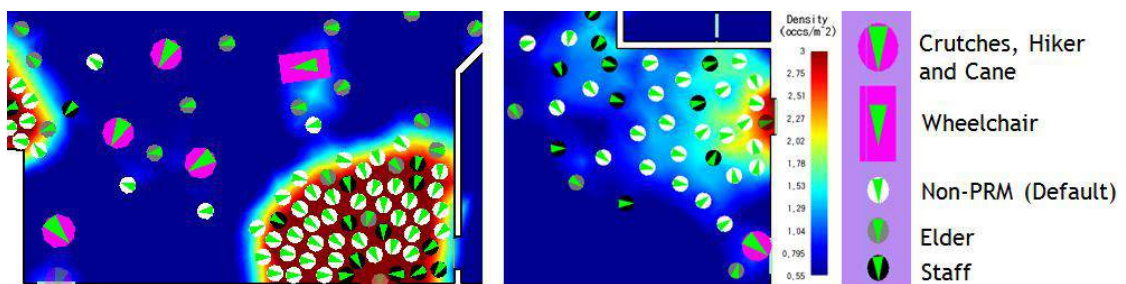
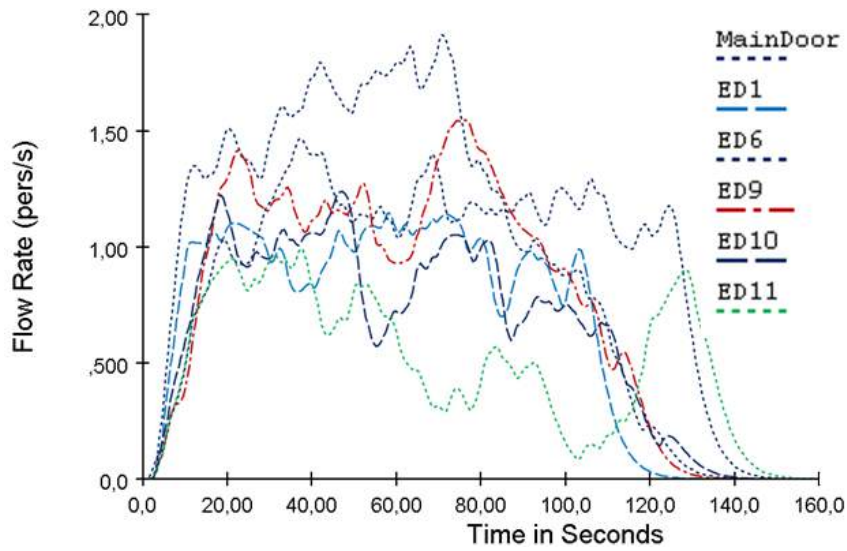
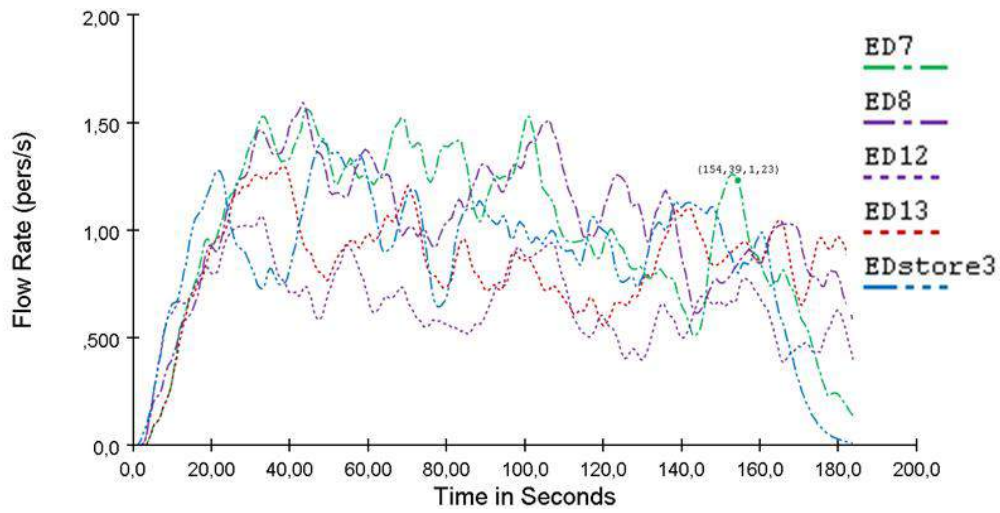


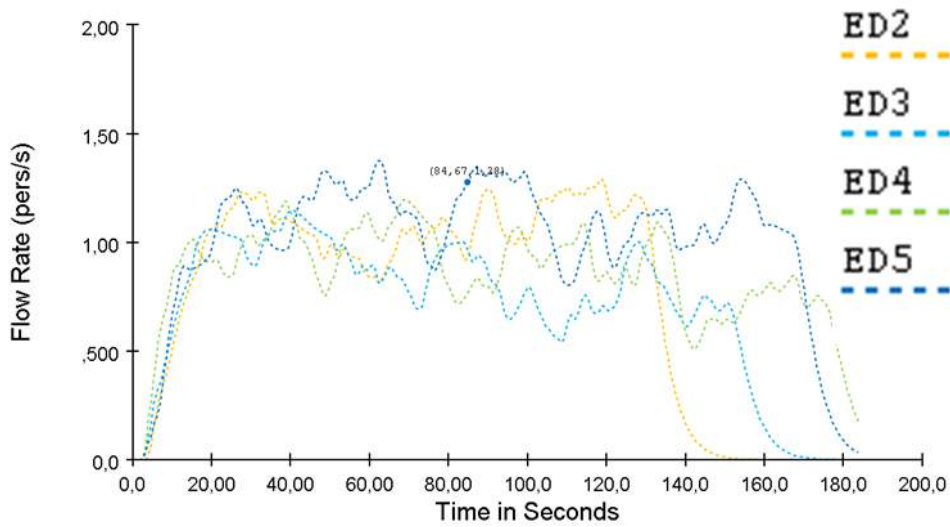
Figure 68: PRM Exiting through PRM Emergency Doors as Planned



Graphic 6: PWA Exit Doors Flow Rate in Simulation 3



Graphic 7: BWA Exit Doors Flow Rate in Simulation 3



Graphic 8: BWA2 and FBS Exit Doors Flow Rate in Simulation 3

#### 4.4.4 Fourth Simulation

In this scenario the addition of separation walls beside the PRM emergency doors was analyzed. The occupants' profiles and behaviors of the third simulation were maintained. These data are described in sections 4.3.1 to 4.3.5 of this chapter, and in Annexes 5 and 6. In Figure 69 the results of this simulation are resumed. Figures 70 and 71 proof the fourth simulation results/outputs and Graphics 9, 10 and 11 represent the flow rate of the fourth simulation exits.

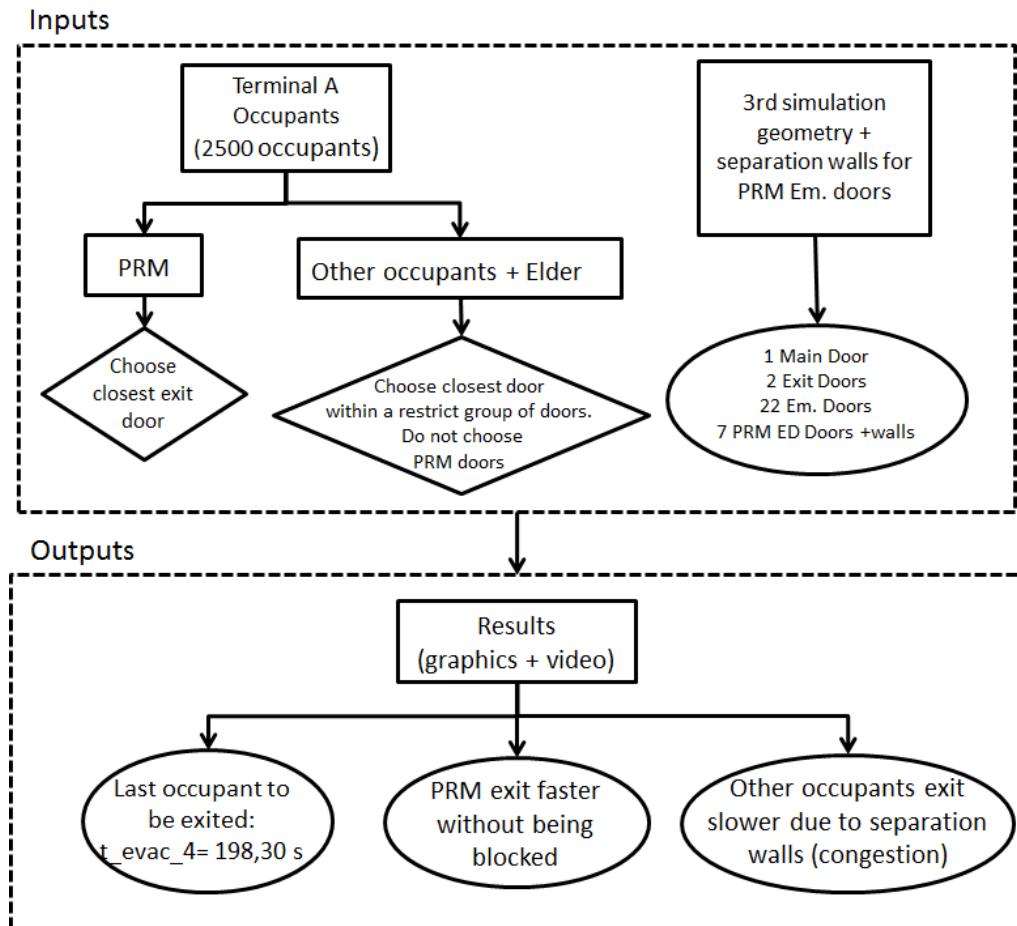


Figure 69: Terminal A Simulation 4 Results (Inputs and Outputs)

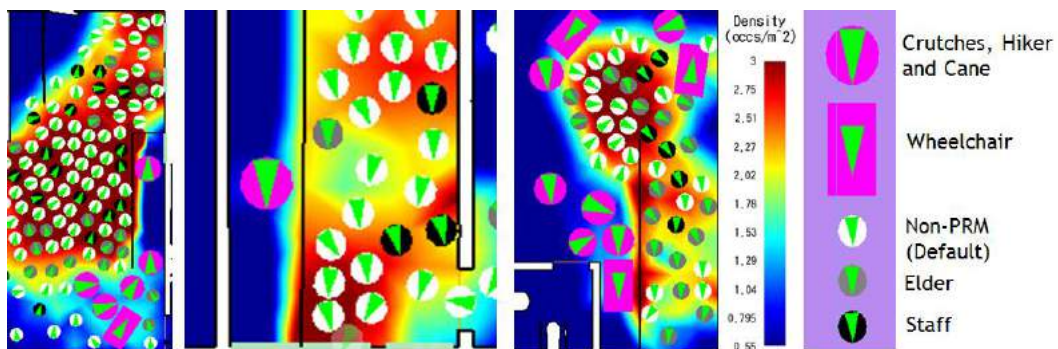


Figure 70: PRM Emergency Doors Correct Operation in Simulation 4

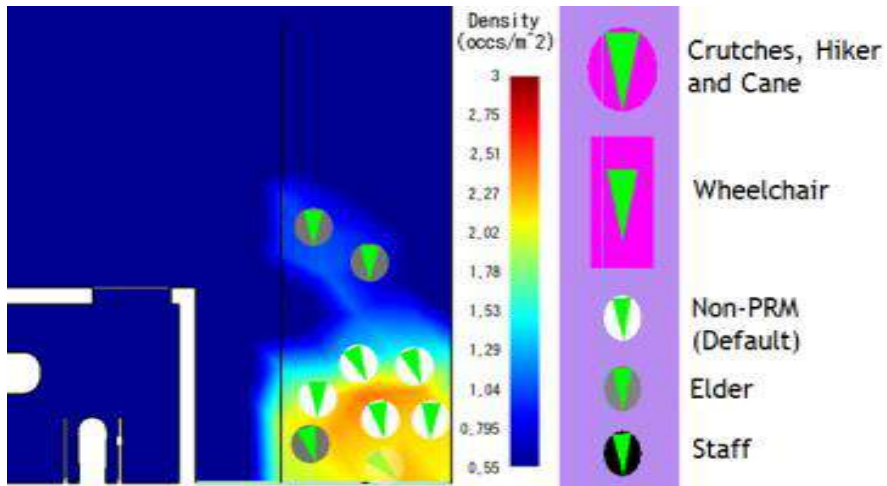
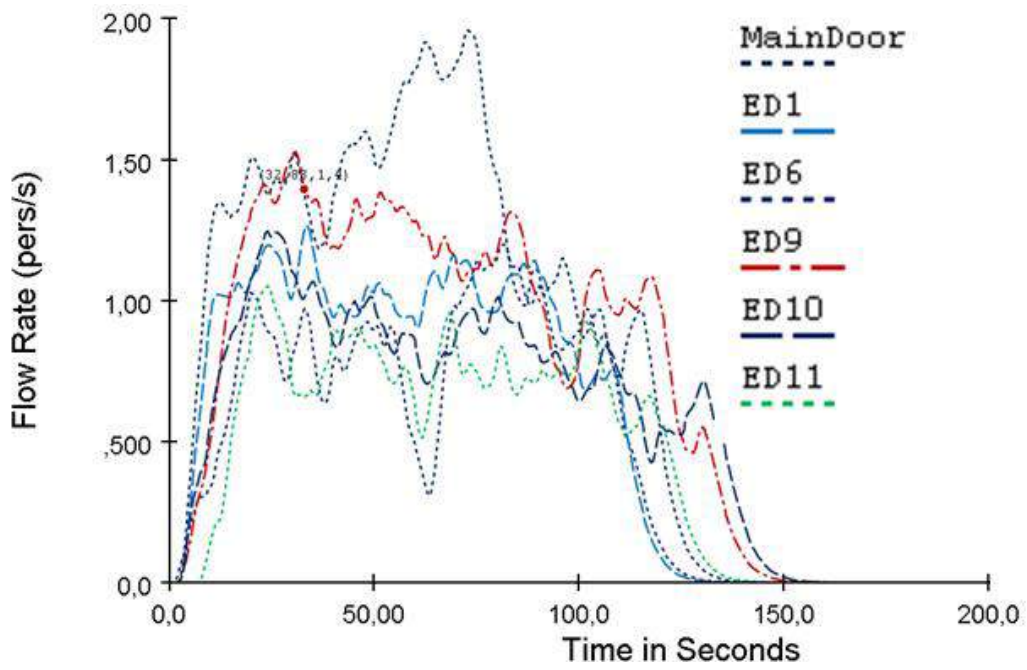
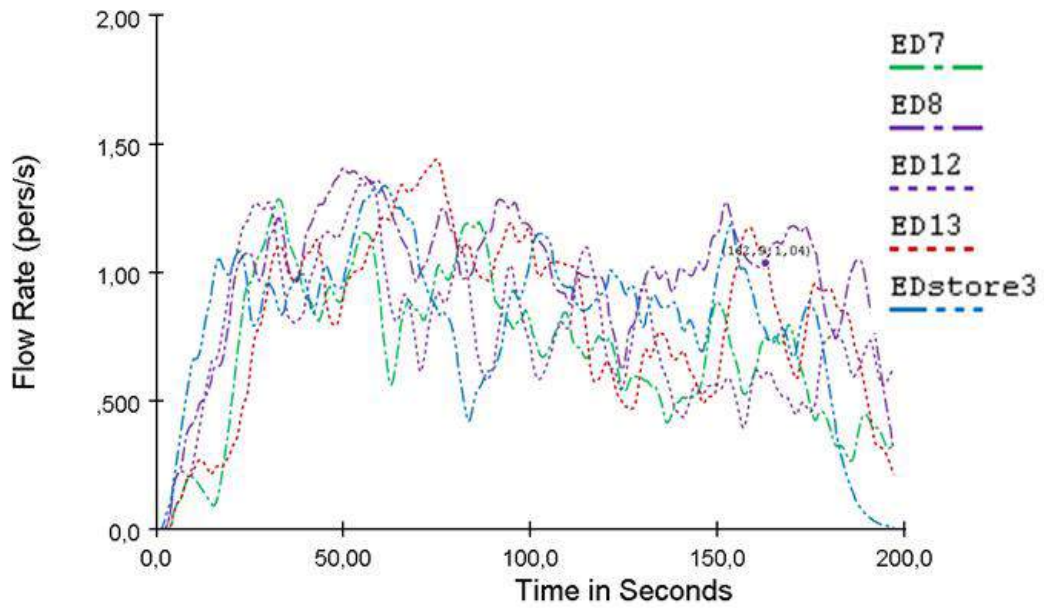


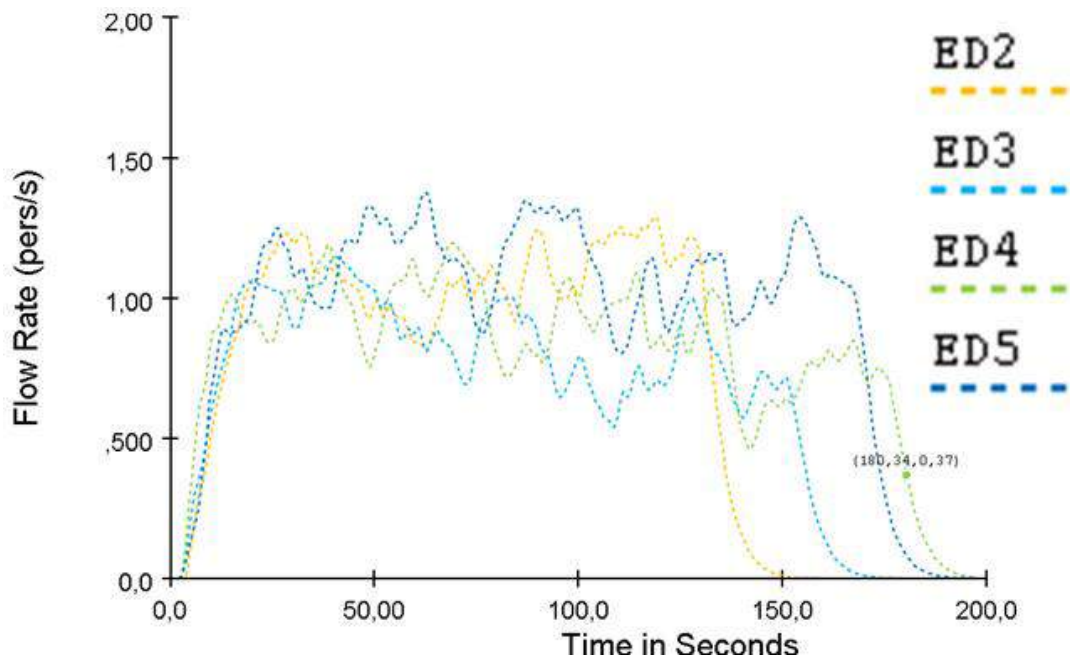
Figure 71: Simulation 4 Last Exited Occupants



Graphic 9: PWA Exit Doors Flow Rate in Simulation 4



Graphic 10: BWA Exit Doors Flow Rate in Simulation 4



Graphic 11: BWA2 and FBS Exit Doors Flow Rate in Simulation 4

#### 4.4.5 Fifth Simulation

As suggested in fourth simulation, a new strategy was studied in this simulation: the implementation of two exterior ramps that allow the first floor occupants to exit through an exterior exit (without using the interior stairs).

Thus, the inputs were the fourth simulation geometry with the addition of two exterior ramps and the fourth simulation profiles and behaviors with the change of behavior to elder occupants that are now allowed to choose any door according to their location. The inputs parameters are described in sections 4.3.1 and 4.3.6 of this chapter, and in Annexes 5 and 6.

Figure 72 resumes the inputs and outputs of this simulation and Graphics 12, 13 and 14 represent the flow rate of the fifth simulation exits.

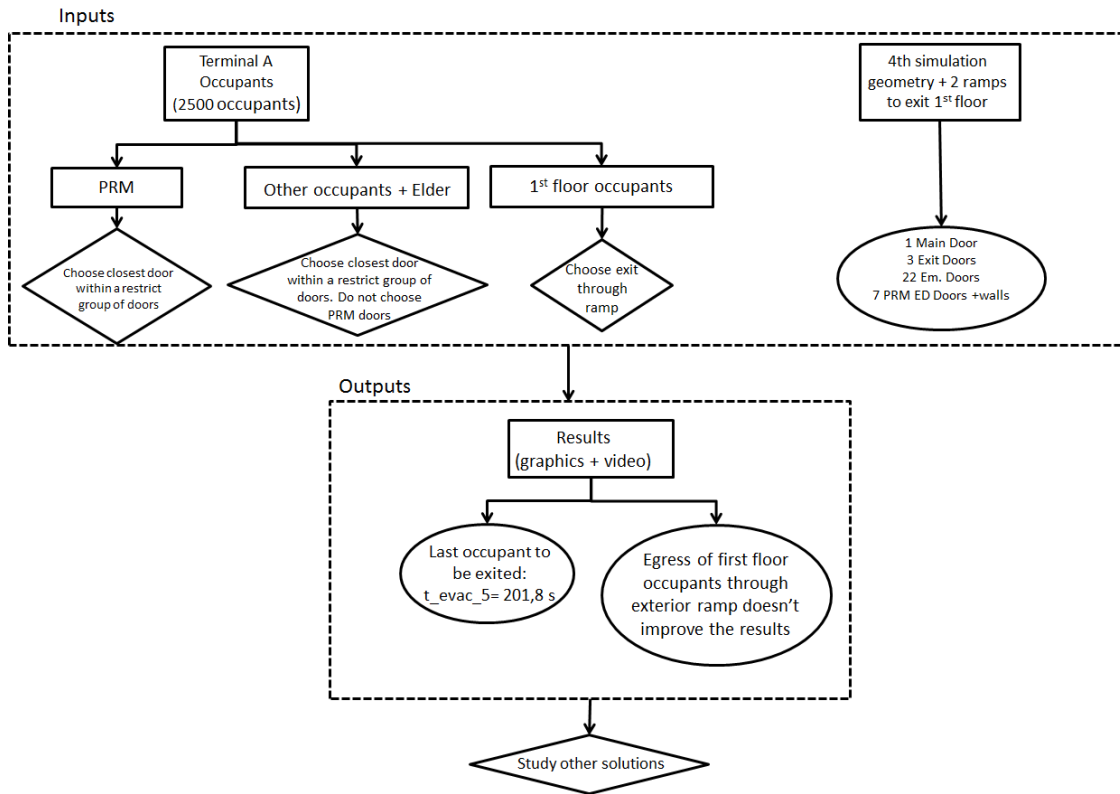
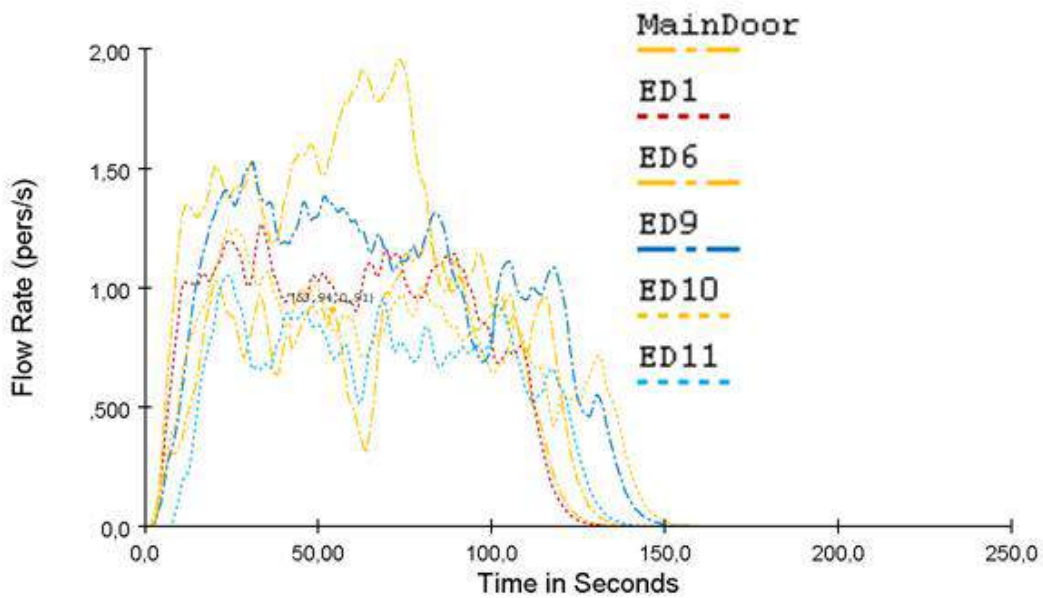
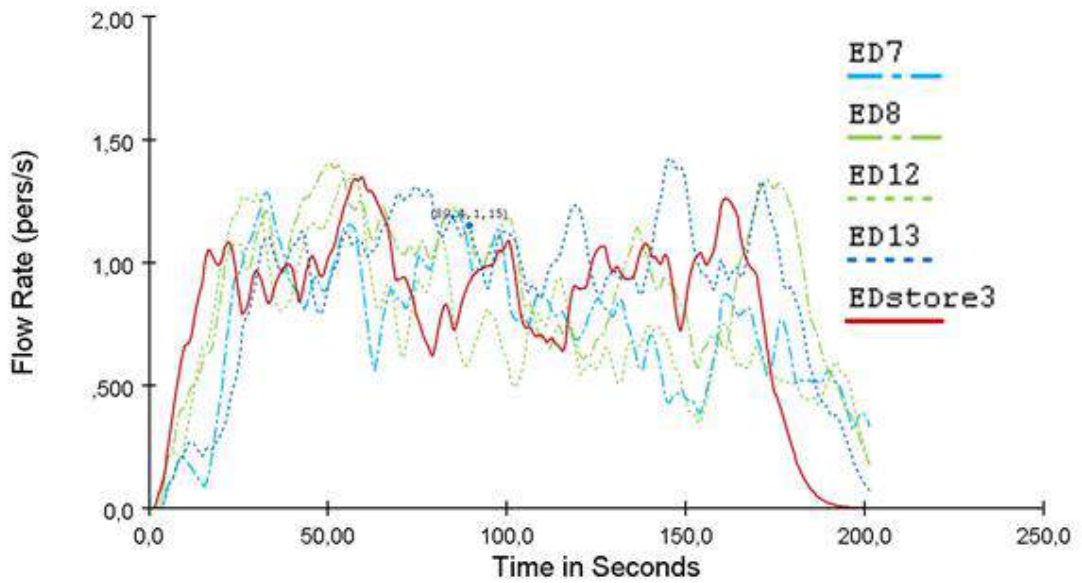


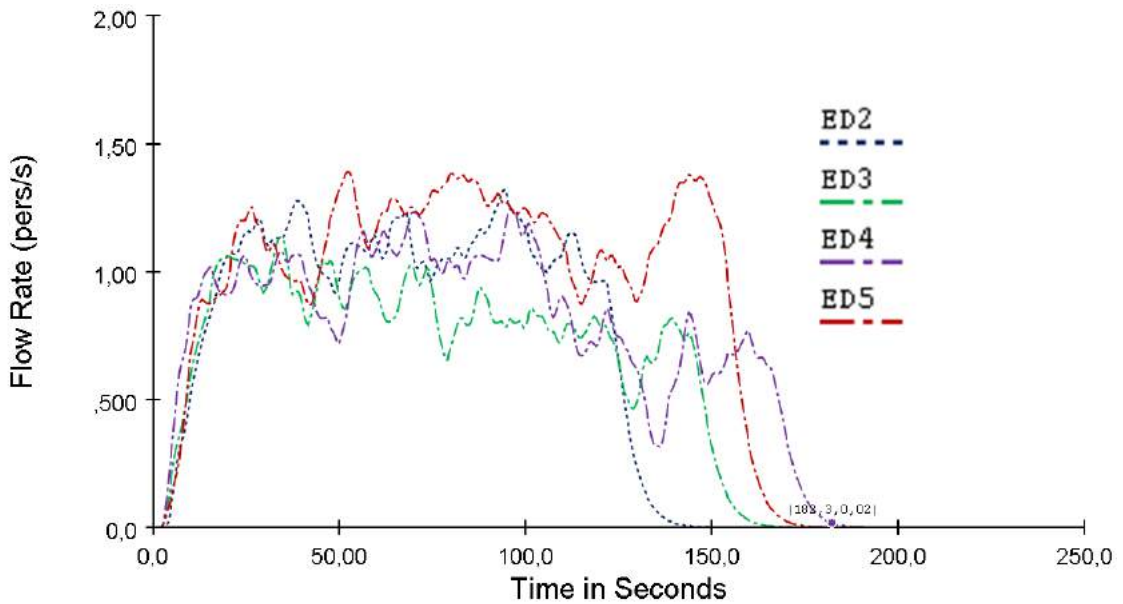
Figure 72: Terminal A Simulation 5 Results (Inputs and Outputs)



Graphic 12: PWA Exit Door Flow Rate in Simulation 5



Graphic 13: BWA Exit Door Flow Rate in Simulation 5



Graphic 14: BWA2 and FBS Exit Door Flow Rate in Simulation 5

#### 4.4.6 Sixth Simulation

For this simulation, was modeled an evacuation scenario where occupants with motor difficulties are given the indication, in case of emergency, to go to the nearest refuge area. Some of the divisions of Terminal A were classified as areas of refuge. This way, new behaviors were introduced that establish each occupant type of evacuation. The inputs parameters are described in sections 4.3.1 and 4.3.7 of this chapter, and in Annexes 5 and 6. The flowchart of Figure 73 shows the inputs and outputs of this simulation. Figures 74 and 75 are the representation of some results obtained and the Graphics 15, 16 and 17 indicate the flow rate of the outputs used in this simulation.

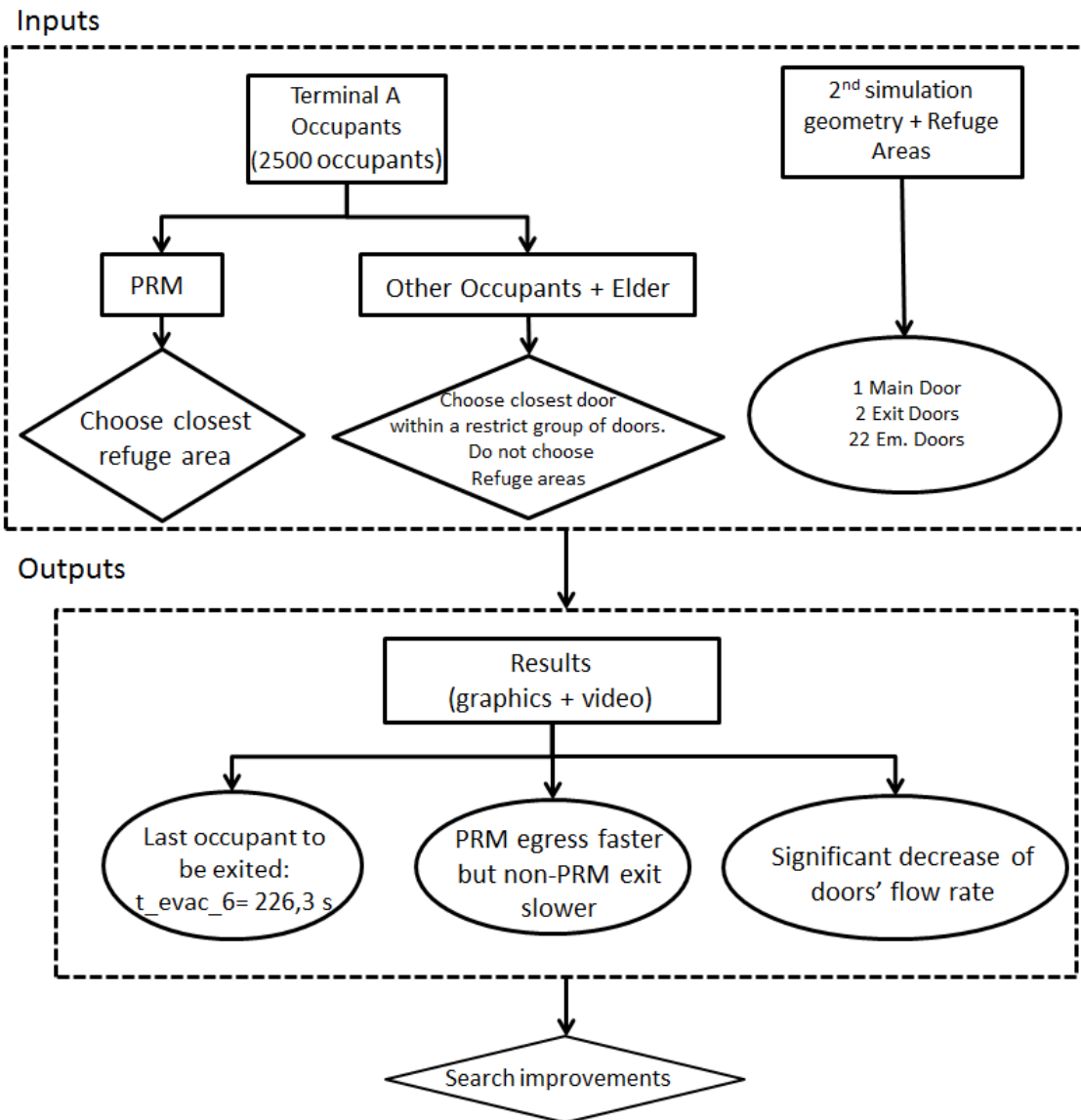


Figure 73: Terminal A Simulation 6 Results (Inputs and Outputs)

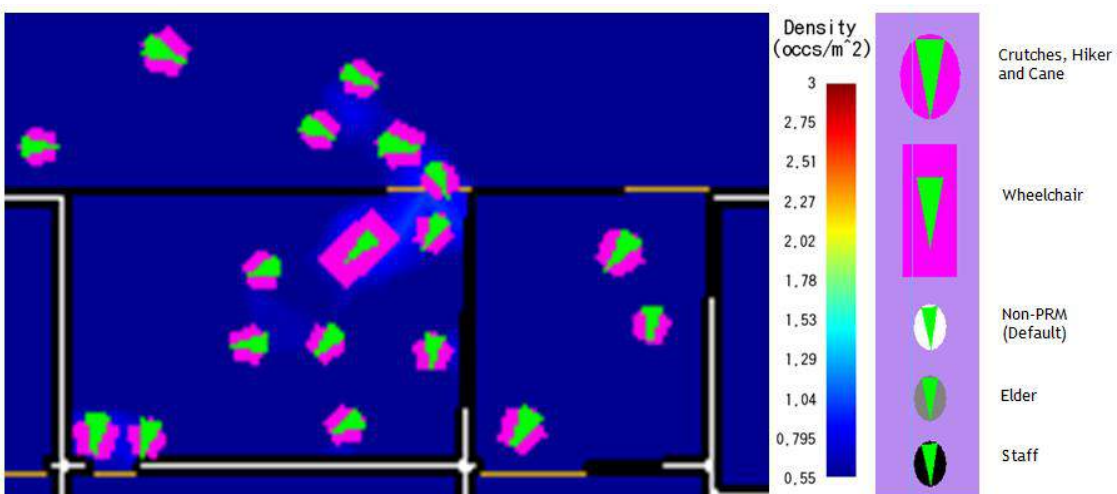


Figure 74: Example of a Refuge Area where Congestion does not Occur (Simulation 6)

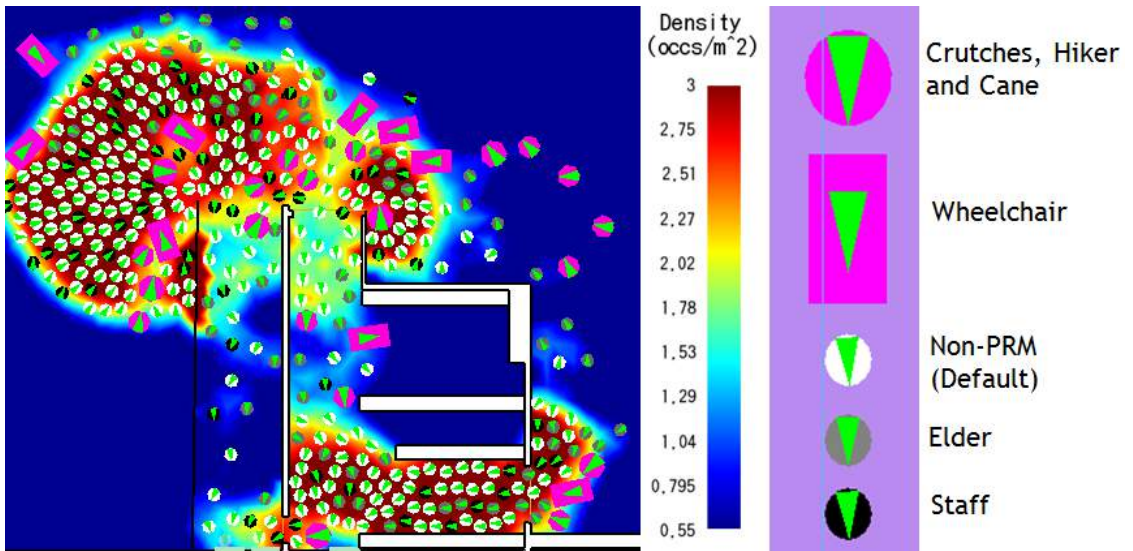
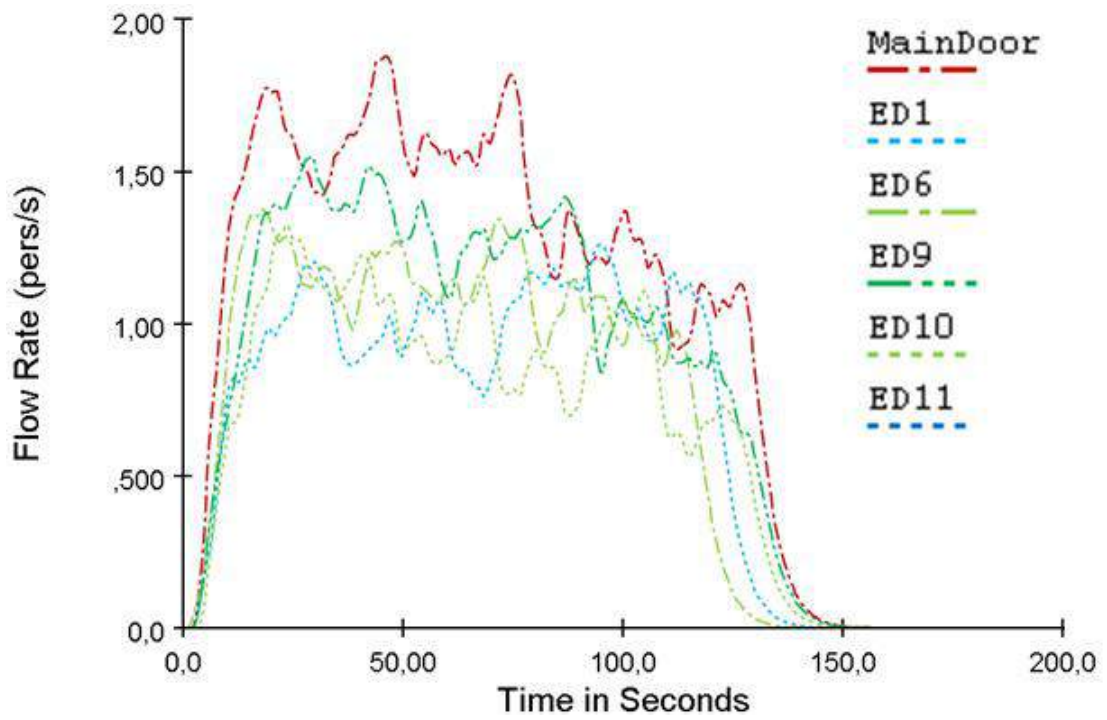
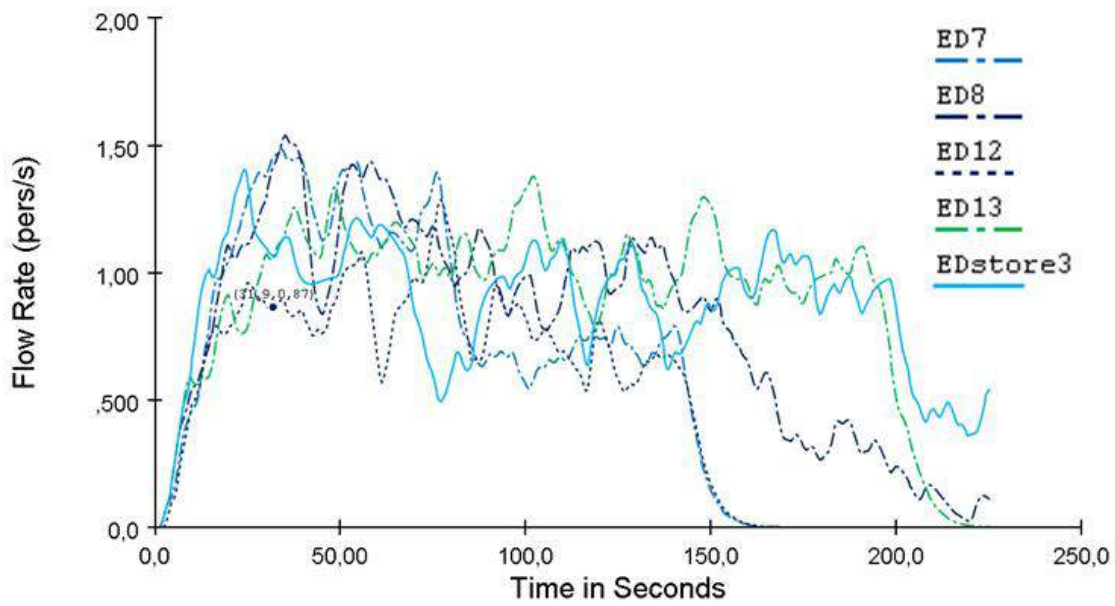


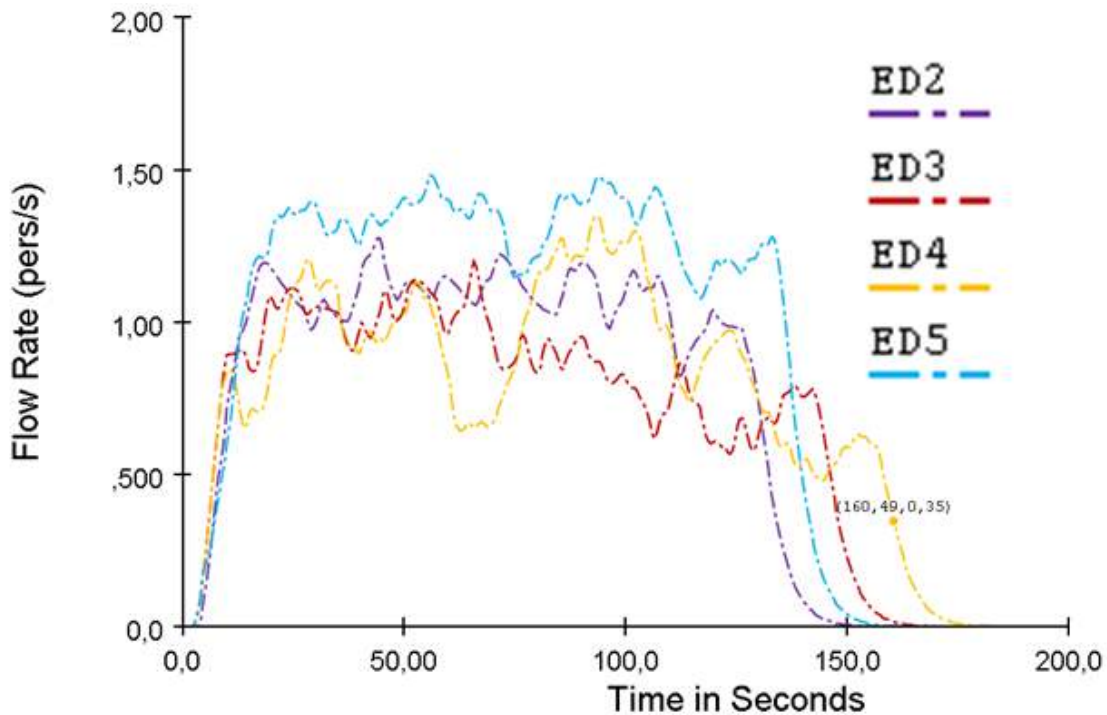
Figure 75: Example of a Refuge Area where Congestion Occurs (Simulation 6)



Graphic 15: PWA Exit Doors Flow Rate in Simulation 6



Graphic 16: BWA Exit Doors Flow Rate in Simulation 6



Graphic 17: BWA2 and FBS Exit Doors Flow Rate in Simulation 6

#### 4.4.7 Seventh Simulation

The scenario modeled in this simulation is very similar to the previous one reviewing once again the advantages and disadvantages of the deployment of refuge areas in Terminal A. The difference is that in this scenario, the PRM expect that an element of an assistance team will assist them in their displacement to the nearest refuge area. This way, new behaviors were introduced establishing the type of evacuation of each occupant. The inputs parameters are described in sections 4.3.1 and 4.3.8 of this chapter, and in Annexes 5 and 6. The flowchart

of Figure 76 shows the inputs and outputs of this simulation, Figure 77 is the representation of the two new behaviors adopted and the Graphics 18, 19 and 20 indicate the flow rate of the outputs used in this simulation.

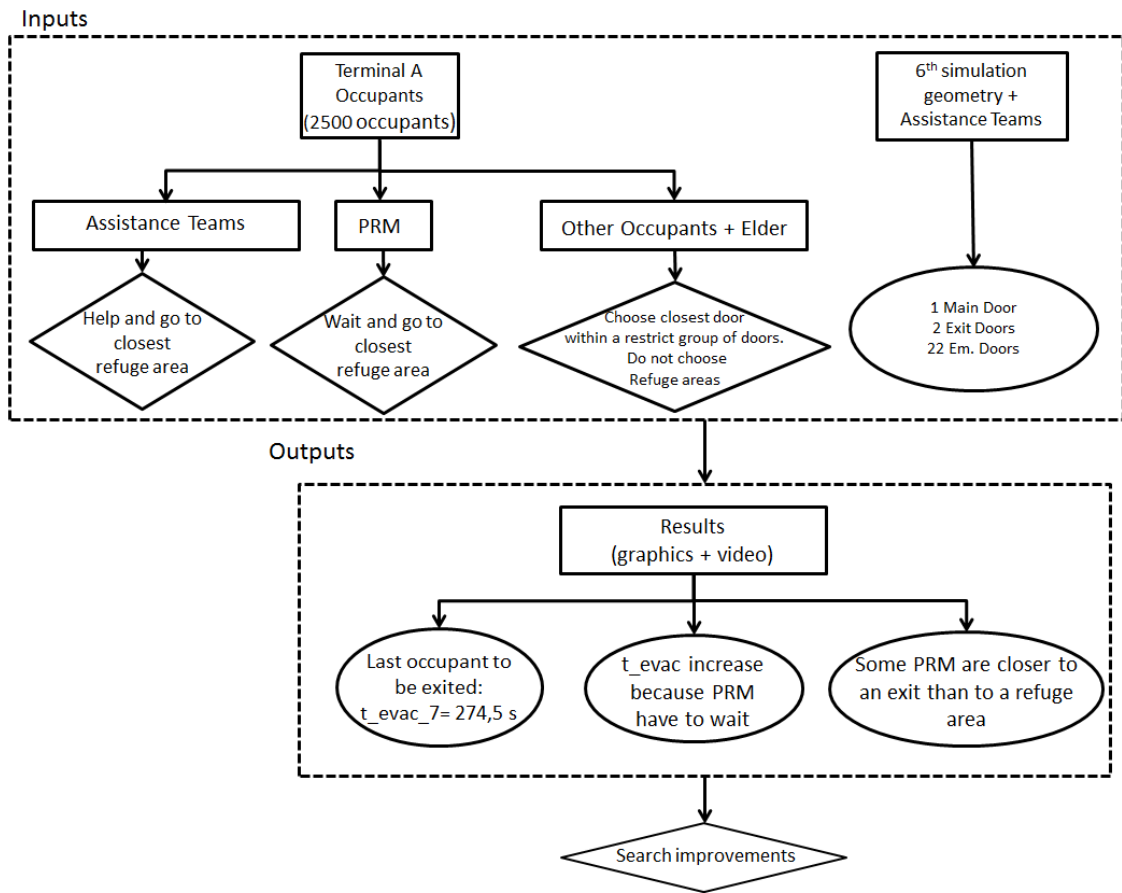


Figure 76: Terminal A Simulation 7 Results (Inputs and Outputs)

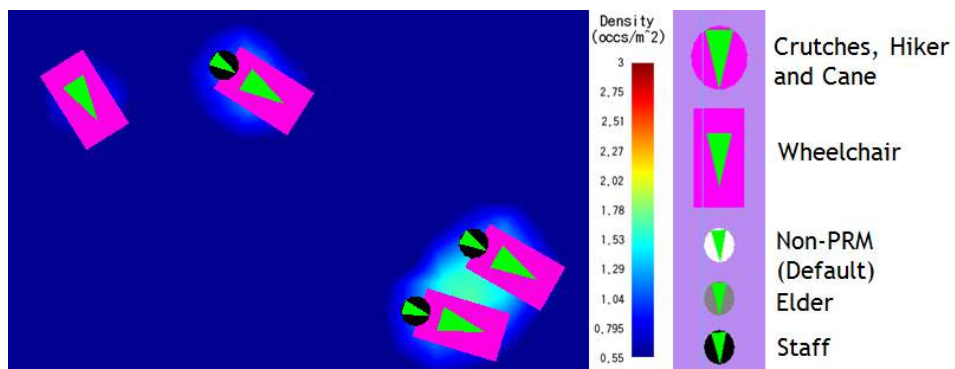
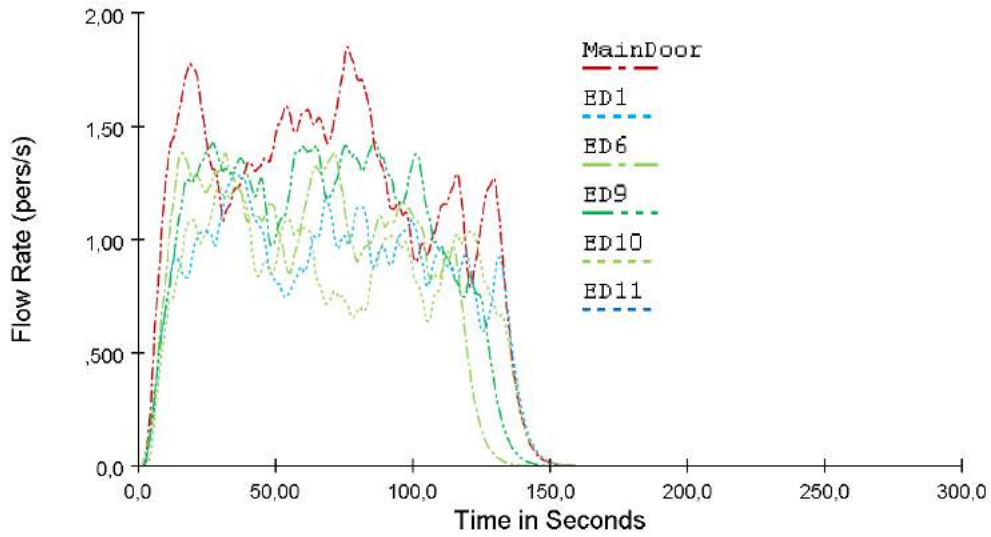
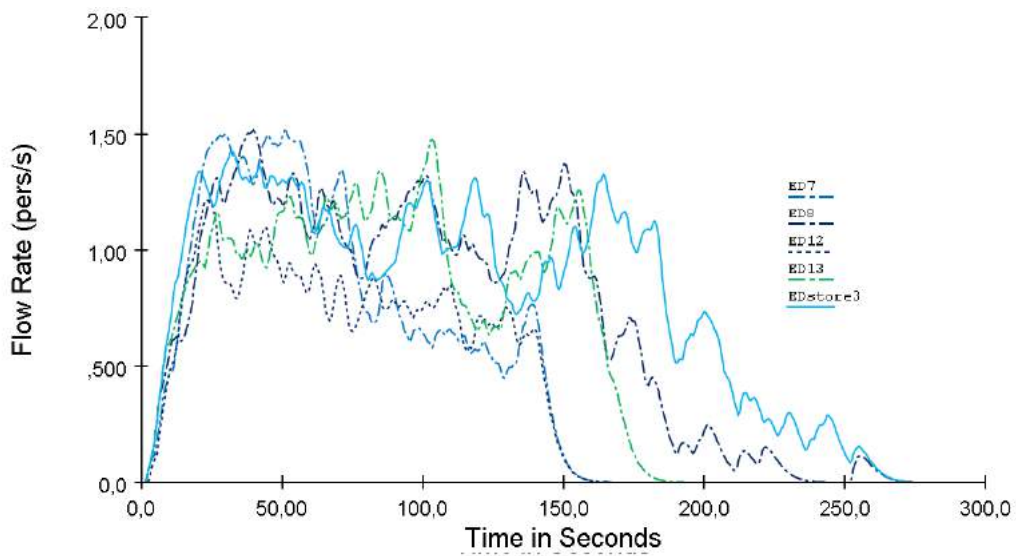


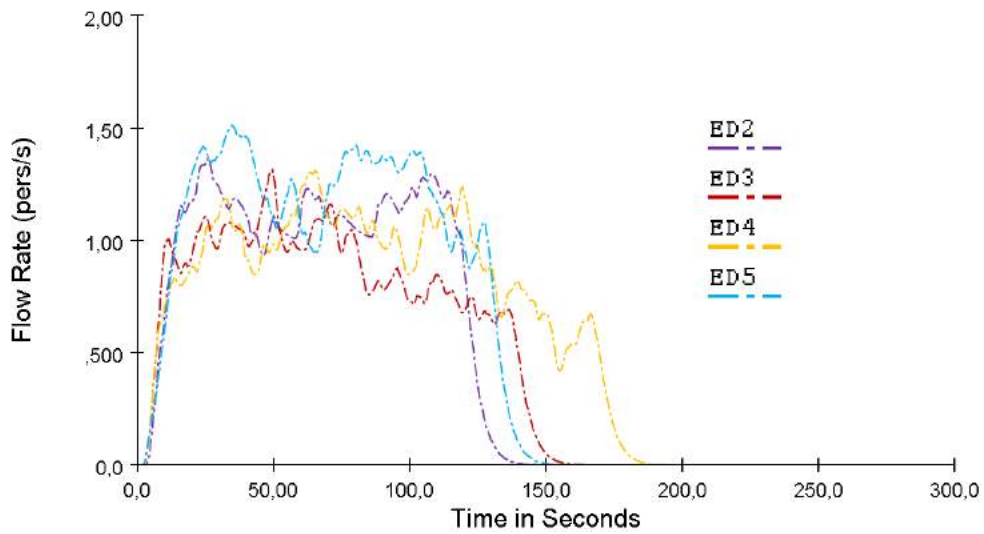
Figure 77: Occupants being Assisted by Staff and Occupants Waiting for Assistance



Graphic 18: PWA Exit Doors Flow Rate in Simulation 7



Graphic 19: BWA Exit Doors Flow Rate in Simulation 7



Graphic 20: BWA2 and FBS Exit Doors Flow Rate in Simulation 7

## 4.5 Conclusion

In this chapter the case study, Terminal A, features and parameters and five simulations (and their respective parameters) were described.

The evacuation simulation model used was *Pathfinder* because of all the characteristics mentioned before (and in Annex 2) and because it was proved (in Chapter 3) to be a valid tool that generates valid results. It is important to mention that the open source factor was very important to decide the utilization of this egress simulation model too.

It is extremely important to refer that are a group of settings that were assumed to all the eight simulations that must be consulted in this chapter or in Annex 5.

All simulations maintained the infrastructural geometry of Terminal A, and all were simulated with 2.500 occupants.

However, each simulation had different occupants' behaviors and different egress exits and infrastructural additions to understand the best configurational solution. The parameters and features of all simulations are specifically described in Annexes 5 and 6.

Through the simulation results we conclude that the solution that improves Terminal A evacuation time is the one modelled in simulation number three because the evacuation time had its lowest result. In fifth simulation the strategy applied did not improve the results but other solutions and strategies should be studied to find the best result for Terminal A. Despite the higher evacuation times, the fourth, sixth and seventh simulations represent acceptable evacuation strategies regarding PRM, when comparing the related results with those of Simulation 1.

The choice of the best solution among all these results could only be made if there was an evaluation or reflection on the opinions and preferences of the PRM. In other words, some of the solutions presented imply that the PRM stay inside the threatened building (in refuge areas) or that they wait for assistance and, of course, some PRM will feel safer if they self-evacuate, or if they go to the refuge areas or if they are assisted by qualified staff.

Again it is important to note that the solutions presented were modeled assuming that occupants unconditionally respect all behaviors, constraints and priorities. In the next chapter these aspects will all be analyzed from a more critical and analytical point of view.



# Chapter 5 - Discussion

## 5.1 Introduction

In Chapter 3 the *Pathfinder* tool was validated and proved trustworthy, so in the fourth chapter Terminal A (the case of study) was analyzed with this tool and several outputs were obtained. This validation allowed assuming that all the conclusions of this chapter are reliable and solid conclusions.

In this chapter, the obtained results and outputs in the simulations are discussed by observing the videos and the figures in Chapter 4 that help us to understand some specific situations in each simulation that are sentenced. It is also available additional information in Annexes 7 and 8 to a better understanding of the discussion.

## 5.2 Analysis and Discussion of *Pathfinder* Simulation Results

In the first simulation we can make a first analysis of the infrastructure level of accessibility for PRM and for non-PRM and realize (see Figure 57) that with some changes in the building configuration, such as the elimination of unnecessary walls and changing the seating arrangement in waiting rooms and tables in the dining area, increase the ease of passenger movement. We can also observe the difference between evacuations with and without PRM and elder passengers:

### a) Simulation 1 (Sim1):

We managed to realize that there is an excessive congestion of the exits (Figures 58 and 60) which can be reduced by creating more emergency exits at strategic locations (such as in stores and in some restricted areas).

Also, we observe that, due to the movement and the clash between passengers, some PRM are being blocked and are the last to leave the building. If we observe Figure 61 we realize that as the time passes PRM occupants are pulled away from the exits by other occupants and end up being the last exited. The evacuation time in this simulation was 733,3 seconds.

### b) Simulation 1A (Sim1A):

The evacuation time for this simulation was 568,8 seconds (with a difference of 164,5 seconds from simulation Sim1). To better understand the configuration of the terminal and to understand how occupants interact with each other were the main purposes to simulate the egress of a building with only non-PRM occupants.

If we carefully observe both scenarios we conclude that in Sim1 the collision between PRM and non-PRM occupants led to a bigger delay than the collisions between Sim1A occupants' collisions. In Sim1A, if a collision occurs the occupants react faster to it and continue their movement to an exit. On another hand, if a collision involving non-PRM and PRM occupants (in Sim1) occurs the non-PRM react slower than in Sim1A but continue their movement and the

PRM occupants react very slowly to the collision and appear to stop and let other occupants to overcome them. In addition, they restart their egress only when they have space to move with comfort. All of these behaviors prove us that because PRM and non-PRM occupants have different physical characteristics (like the velocity, shoulder width, etc.) and react to collisions differently than other occupants, the evacuation times to the both groups are slower. Therefore, it is a matter of equity to try to implement strategies that do not decrease their evacuation times or even attempt to improve these times.

When we compare Figure 58 with Figure 59 it is conclude that this simulation some congestion in specific places is a result of a not so good configurational design.

At the end of this first simulation (Sim1 and Sim1A) we conclude that there are some problems that should or must be solved:

- Configurational and design problems (unnecessary structures, bad sitting and service counters configuration that should be rethought);
- PRM occupants are blocked by the others and exit in last;
- There is an extreme congestion in every exit.

In an attempt to decrease the exits' flow rates, the assignment of behaviors to occupants according to their location (restring the door choice) should be tested.

In the second simulation, emergency exits were added to the terminal configuration in strategic locations and, in an attempt to reduce the evacuation time, there were still assigned behaviors that restricted the choice of the exit door to certain groups of occupants.

With the increased number of exits some areas are evacuated more quickly and, therefore, the evacuation time decreased for 191,3 seconds. This also happens due to the removal of the unnecessary walls and counters (Figures 63 and 64).

Observing Graphics 1 to 5 it is concluded that there was a significant diminution of the exit doors flowrates due to the allocation of more behaviors. The application of all of these strategies resulted in registered evacuation time decreased of 542,0 seconds from Simulation 1.

At the end of this simulation, PRM occupants are still being blocked) and this issue can be solved by adding priority emergency doors ("PRM\_ED" doors), for example. For this addition, a new behavior must be assigned to allow PRM to use them and do not allow other occupants to use them.

In the third simulation, the number of exits remained the same as in the previous simulation (second simulation). However, in order to avoid collision between the occupants without and with mobility constraints, priority emergency doors were added as a horizontal displacement evacuation strategy. There were therefore added two new behaviors that allowed the PRM (excluding elder occupants) to access priority exits and forbid this access to the other

occupants. That is, PRM choose the closest exit door (including the priority door) and the other occupants choose the closest exit door (excluding the priority doors).

Observing Graphics 6 to 8 and comparing them with Graphics 3 to 5 it is concluded that there was a small diminution of the exit doors flowrates due to the allocation of these new behaviors, resulting in a registered evacuation time decrease of only 7,0 seconds from Simulation 1. It is believed that this decrease was so low because of the occupants' exit door decision process.

In all simulations is assumed, by default, that an occupant (in this case based in calculations done by the simulation tool) first evaluates what is the nearest exit door and then chooses it. When two or more doors are at the same distance the occupant attributes the same priority to these doors (35% in this case) and chooses randomly one exit door. This means that when a PRM occupant had to choose between a PRM\_ED door or another exit door (that are both at the same distance from his location) the PRM may not chose the PRM\_ED door as supposed.

Therefore, it was interesting to model this scenario with the same parameters in the same simulation tool that establishes a detailed door choice process (where PRM occupants attribute a higher priority to the PRM exit doors) to its occupants and to understand if this decrease would be higher (as expected). It would also be interesting to elaborate a cost and benefits evaluation of this scenario, look at the results, and try to understand if an airport advisory board would decide to proceed, or not, with the addition of these priority doors.

From the outputs, we conclude that because of the addition of priority doors some PMR can reach doors faster and consequently the evacuation through the emergency doors happens more quickly (less crowded). As we can see in Figure 68, in bigger places PRM occupants reach easily the priority doors and evacuate faster (without being blocked).

However, we also observe that, in smaller places, as the collision between the two groups of occupants still difficult access to priority doors, PRM continue to be delayed and do not leave the building as soon as it was expected (see Figure 67). Therefore, blocking between PRM and other occupants still happen the PRM are once more delayed and exit in last. A solution to this problem may be the addition of separation walls beside these exits to avoid the blocking.

In emergency situations this priority and these behaviors would probably not be respected by the other occupants. However, this solution speeds up the evacuation process of the building and allows the PRM to be evacuated much earlier than in other situations. It is therefore important to realize that implementing this strategy would only be beneficial if all occupants are well informed about evacuation procedures, if the building has available and up-to-date information about evacuation procedures and escape routes on every division, and if has appropriate signage so that each group of occupants can easily understand what is the best evacuation route appropriate to each type of mobility and... follow it.

In simulation number four separation walls were added to the priority doors in order to avoid the collision between the two groups of occupants. In one hand, this strategy allowed PRM to reach the PRM\_ED doors faster (Figure 70) and also, for the first time in all the simulations, the last occupants to be exited in simulation are not PRM ones (Figure 71). On the other hand, when a detailed observation of Graphics 9 to 11 is made, it is concluded that the existence of these walls resulted in a higher collision rate between the other occupants because now they have less space to reach the exit doors located beside PRM\_ED doors.

Once again, in a real emergency situation, occupants may probably neglect the doors restrictions and priorities and this particular scenario results would certainly encourage them to do so. That is why it is so important to inform people about evacuation procedures and raise awareness regarding different evacuation strategies for different types of mobility.

We can conclude that simulation number four resulted in an increase of the registered evacuation time of 14,0 s from the previous simulation but that doesn't forbid the study of the application of new strategies to find new improvements.

So far, the occupants of the first floor were always evacuated through the ground floor. Thus, in this simulation the evacuation of the occupants of the first floor was taken through two exterior ramps.

Observing the Graphics 12, 13 and 14, it is concluded that this amendment only triggered a minor congestion decrease in FBS and BWA exit doors during the first seconds of evacuation. Thus, this decrease did not affect severely the evacuation time revealing that this change was not considered significant. It is also observed that the first floor occupants take longer to exit the building because they have to choose a longest egress route

Therefore, the evacuation time result of the fifth simulation has registered a value of 201,8 seconds and the implemented strategy did not improve the Terminal A egress process. From the outputs of this final simulation we observe that the egress of the first floor by an exterior ramp doesn't improve significantly the evacuation time (results in a 3,5 s increase) and requires major financial investments and big infrastructural alteration.

The release of *Pathfinder* 2017 version was very convenient once its new features made possible the enrichment of this work and so, two more simulations were modeled.

In the sixth simulation was made the resort to zones of refuge. These refuge areas are spaces within a building constructed with different materials so that its structure is capable of remaining intact during any emergency situation. This way, heading for a zone like these is equivalent to heading to a completely safe zone.

Therefore, a new behavior was attributed to the PMR who, this time, instead of going to an exit they will choose to move to the nearest refuge. As in previous situations, the other occupants will assume that these areas are intended for PMR only and continue to choose an exit from the building.

In order to not change the geometry of Terminal A, these zones were placed strategically in existing divisions in the terminal. For this reason, in some of these areas, the PRMs were being blocked and they entered the refuge zone later. In Figures 74 and 75 this behavior can be observed, and it only occurs because, by default, this new version of *Pathfinder* allows the refuge areas to be crossed by other occupants.

If Graphics 15, 16 and 17 were analyzed it is possible to understand that the evacuation time increased in this simulation because the occupants that decided to exit through the door “EDstore3” had to move inside a refuge area. It is concluded that the location of this refuge area is not advantageous and that designers (or others responsible for planning a building evacuation plan) should have this in mind.

It is also concluded that the evacuation time increased because some PRM, that where near to an exit door, had to describe a longer egress route to reach a refuge area.

The seventh, and last, simulation was similar to the previous one but this time PRM occupants have to wait for an assistant and some of the staff occupants were assigned as members of an assistance team that have to assist PRM moving to a refuge area, then help other PRM (if there are more passengers waiting for assistance), and finally remain in the refuge area with the PRM. Figure 77 show us this behavior that, as expected, increased the evacuation time. Graphics 18 and 19 show us that this increase occurs because PRM have to wait for assistance and that some of them have to wait even longer because there are just a few assistants.

It is important to remind that this last simulation represents the actual PRM evacuation procedures in airports and that this simulation evacuation time is higher (90,2 s) than the one obtained in Simulation 3.

Once more, compliance with constraints and priorities during a real evacuation is questionable and, in this particular case, it would be natural to observe PMR to leave the building even knowing of the existence of refuge areas because being inside a building when its structure is to be threatened is seen as anti-natural behavior.

It would be interesting to note PRM's views on these strategies and also to see how these strategies could be improved (for example with wheelchairs with a geographical location chip).

### **5.3 Conclusion**

In this chapter, the results of the *Pathfinder* simulations were analyzed and all the conclusions about each simulation scenario were sentenced. It is important to remember that these simulations had a group of modelling parameters (like type of incident, occupants' profiles, and others) that remain the same in all scenarios.

With these results, it is easily understood which evacuation strategies work and how they can and should be implemented.

As expected, and proved in Simulation 1A, the evacuation time of occupants with mobility restrictions is bigger and therefore different evacuation strategies, appropriate to each type of constraint, should be implemented.

Through the results, it is also observed the building level of accessibility to each type of mobility impairment and we easily understand which configuration and infrastructural modifications would improve movement inside de building. In the second simulation, the implemented alterations proved that the Terminal A configuration and design directly affects the occupants' movement and, consequently, the evacuation times. Therefore, some more configurations and accessibility alterations should be studied in the future.

The third simulation has the lowest value for evacuation time and the model scenario studied the use of priority emergency doors for PRM.

Fifth simulation was an attempt to improve the fourth simulation results by evacuating the first floor occupants through an exterior ramp. The adoption of this strategy would obviously involve major infrastructural changes and large financial investments. However, this simulation results shows that there was not a decrease of the evacuation time when compared with the fourth simulation. Thus, it is considered that the configuration and the parameters adopted in the fifth simulation would only have obvious advantages if, eventually, the access to the ground floor is blocked, requiring the evacuation of the first floor occupants through an alternative way.

Simulations 6 and 7 are about the use of refuge areas and assistance teams. The solutions found in simulations 3, 4, 6 and 7 would probably not present the same results in a real emergency situation because often occupants do not know how to proceed correctly in an evacuation scenario and follow their own instinct. Consequently, the behaviors assigned in these scenarios would all be disrespected. Information about evacuation procedures should be clear and made available so each occupant could choose the best egress route according to their mobility type. Raise awareness it is also important to discourage non-PRM occupants to use the evacuation strategies for PRM.

It is believed that these seven simulations (with Simulation 1 divided in Sim1 and Sim 1A) were enough to better understand the factors that influence the evacuation of a building when PRM occupants exist; so no more simulations were conducted. However, it is encouraged to conduct more simulations with different evacuation strategies as future work.

Finally, we may conclude that there is no solution that we can point as the ideal one for Terminal A; all the modeled strategies have advantages and disadvantages. However, if we decide to assume that time is the sole criterion, Simulation 3 would be the one selected since it has the lowest evacuation time.

These assumptions can be done only because in Chapter 3 the *Pathfinder* simulation tool has been considerate reliable.

## Chapter 6 - Conclusions

### 6.1 Dissertation Synthesis

Emergency situations at airports are becoming frequent. In fact, at any time, due to factors we do not control, there may be an emergency at an airport.

People with reduced mobility are almost never taken into account in building evacuation plans and, when they are, it rarely meets their real needs. Most of the buildings where these people are taken into account are medical or hospital infrastructures.

Air transport is not much associated with the transport of such passengers. However, with an aging population and a greater range of destinations with attractive prices, this group of passengers chooses air transportation with more frequency. Arises, therefore, the need to review and adapt the evacuation plans to the needs of PRM.

In the beginning of this study it was set that the object of this dissertation was the infrastructure emergency evacuations, the factors that influence the evacuation in a building, the evacuation procedures of dependent populations and major evacuation constraints of passengers with reduced mobility and the evacuation simulation tools used to analyze infrastructures.

And it was also set that the main objective of this study was divided in two sub-objectives: the validation of a specific evacuation simulation tool through the analyses of an industrial building with real data and the implementation of this tool in the analyses of an imaginary airport with similar characteristics of Portuguese airports.

For the preparation of this study it was made a contextualization about emergencies at airports, which factors influence the evacuation of buildings, who are the passengers with reduced mobility according to the air transport legislation, which rights and duties they have and how they are addressed in current evacuation plans. Some existing solutions to improve the evacuation of PRM were presented too.

The importance of good evacuation plans and conducting frequent drills was mentioned and when they cannot be carried out or carry monetary damages, the concepts and characteristics of evacuation simulation tools are a valid alternative.

Once selected a simulation tool, the validation with real and reliable data of the software was proceeded.

For this validation, *Joalpe* represented an extremely important role because with the data provided by the enterprise it was possible to simulate six evacuation drills specific scenarios. The results of these simulations proved to be very close to the real results reported by *Joalpe*. As the results were similar, *Pathfinder* was proved valid and it can be used to analyze

other infrastructures. Therefore, the first sub-objective of this dissertation was successfully achieved.

Concluding that the tool was valid, simulation of various evacuation scenarios in an airport terminal where conducted. The obtained results showed that routes and specific emergency exits for each type of mobility can optimize the evacuation times.

In the discussion of the Terminal A simulations results it was concluded that more emergency doors should be placed in strategic locations, that the solution that evacuates faster PRM occupants is the implementation of priority emergency exits with separation walls (to avoid the block by other occupants) and that the implementation of specific egress routes (by restraining the door choice) is the best way to evacuate the other occupants. It was also proved that the strategies applied in simulations 3 and 4 (priority doors for PRM with separation walls) were better solutions (in terms of evacuation time) than the strategy applied in simulation seven that represents the one applied nowadays in Airport Terminals. With these results, the second sub-objective was considered achieved.

This type of simulation has proven to be an extremely useful tool since it allows the simulation of the evacuation where performing evacuation drills is impossible or difficult to achieve.

Studies like this one, where several types of occupants (with different levels of mobility) are simulated, are extremely important for the assessment of levels of accessibility of buildings and for the implementation or creation of new configurations and evacuation strategies (taking into account the locomotor needs of all occupants), contributing to the improvement of buildings and all its occupants' safety.

## **6.2 Final Considerations**

Meeting the needs of people with a disability or reduced mobility is both a personal and corporate responsibility. Everyone in an organization has a responsibility to ensure they meet the needs of their customers. At the personal level, it involves awareness of the potential needs and requirements of disabled and reduced mobility passengers and the ability to communicate effectively. Those involved in the design, management and delivery of services should have a clear understanding of how their role affects disabled people, and the knowledge, skills, abilities and commitment to ensure that disabled people are included.

According to all faults of information, signage and structural alternatives designated before an infrastructure revision must be done and include not only the physical access and ease of use of facilities but also operational manuals, emergency procedures, evacuation arrangements, safety information and other documents. It will be needed to take into account of new practices and technologies too.

An individual with a disability or mobility difficulty knows better how his/her needs can be met. Therefore, staff should always seek to understand this through dialogue with the

passenger, rather than making assumptions. Passengers should be allowed to exercise self-reliance wherever possible. For example, a blind person who is able to walk through an airport should not be forced to accept wheelchair assistance.

It is natural that those legally responsible for the airports safety question themselves about the best strategy evacuation of its occupants in the event of emergency, minimizing the necessary investment for its implementation, factor certainly very relevant in the current times, without putting into question its efficiency and effectiveness.

Obviously better than have a good response plan for emergency is to have an effective prevention plan. However, even for the best prevention plan, there are variables which organizations have no control, whether internal or external, and that can trigger emergency situations.

In this circumstance, the key question is: What's the best evacuation strategy? To answer the question, one of the key criteria is to know the degree of dependence of the occupants of the facility in terms of mobility, perception and reaction to emergency situations and emergency detection systems.

Therefore, our opinion is that the emergency plans of the airports, and particularly their evacuation plans, should have the necessary flexibility in order to incorporate the most appropriate strategies to the specific characteristics of their human occupation, being normal to consist of several evacuation strategies.

Given our ageing population, longer working lives and higher density living, it is critical that we start to prioritize the importance of a universally accessible egress route from all buildings, including residential buildings and change legislation to reflect this requirement.

Moreover, airports, tour operators and travel agents, should make available in accessible formats both general information, as well as specific information about services and emergency procedures for disabled persons and persons with reduced mobility.

Based on the current work, a poster communication and an oral presentation in the 14th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED), in Lisbon, and an oral presentation in ICEUBI 2015-International Conference on Engineering, in Covilhã, were accomplished.

Also, a paper was published in the 14th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED) final proceedings with the title "Constraints in the Airports Emergency Protocols for Passengers with Reduced Mobility" with the ISBN 978-989-20-6262-4.

It is important to recognize that faults against PRM occur because of negligence; so this work is crucial to revival conscientious and alert that evacuation procedures review must be done. It is not what fails but it is what does not exist that matters!

## 6.3 Prospects for Future Work

Due to the current work and acquired knowledge and experience it's believed that the next steps in this work should cross the following investigation lines:

- Simulate more evacuation scenarios in different airports or other buildings to obtain more results and maybe to experience more strategies;
- Explore specific mobility improvements for some particular groups of passengers with reduced mobility, such as blind, deaf and with cognitive disabilities;
- Create innovative evacuation strategies that serve the needs of everyone;
- Incorporate fire, earthquake and other emergency data in the evacuation models to obtain more specific results;
- Compare several evacuation models to real data and between each other in order to contribute to the evacuation simulation tools calibration;
- Do deep and exhaustive investigations on the legal framework regarding safety building regulations in order to understand better the safety mandatory measures and parameters and how disabled are taken into account on this regulation, and also as an attempt to demystify such an ambiguous theme.

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## Annexes



# Annex 1- Summary of Category Labels of Evacuation Egress Models

The models can be distinguished in accordance with the characteristics listed in Table A1-1. The main features of the main models available can be found in Table A1-2 and the special features in Table A1-3 (using the abbreviations in Table A1-1).

Table A1-1: Summary of Main Features Category Labels (Kuligowsky et al., 2010)

Main Features	Label	Meaning
Availability to the Public	(Y)	The model is available to the public for free or a fee
	(N1)	The company uses the model for the client on a consultancy basis
	(N2)	The model has not yet been released
Modelling Method	(M)	Movement model
	(M-O)	Movement/optimization models
	(PB)	Partial Behavioral model
Purpose	(B)	Behavioral model
	(B-RA)	Behavioral model with risk assessment capabilities
	(1)	Models that can simulate any type of building
Grid/Structure	(2)	Models that specialize in residences
	(3)	Models that specialize in public transport stations
	(4)	Models that are capable of simulating low-rise buildings (under 15 stories)
Grid/Structure	(5)	Models that only simulate 1-route/exit of the building.
	(C)	Coarse network

	(F)	Fine network
	(Co)	Continuous
Perspective of the Model/Occupant:	(G)	Global perspective
	(I)	Individual perspective
	Each model is categorized by both the perspective of the model and of the occupant. If only one entry is listed in this column, both the model and occupant have the same perspective.	
	(N)	No behavior
Behavior	(I)	Implicit
	(C)	Conditional or rule-based
	(AI)	Artificial intelligence
	(P)	Probabilistic
Movement	(D)	Density
	(UC)	User's choice
	(ID)	Inter-person distance
	(P)	Potential
	(E)	Emptiness of next grid cell
	(C)	Conditional
	(Ac_K)	Acquired knowledge
	(Un_F)	Unimpeded flow
	(CA)	Cellular automata

	(N)	The model cannot incorporate fire data
Fire Data	(Y1)	The model can import fire data from another model
	(Y2)	The model allows the user to input specific fire data at certain times throughout the evacuation
	(Y3)	The model has its own simultaneous fire model
CAD	(N)	The model does not allow for importation of CAD drawings
	(Y)	The model does allow for importation of CAD drawings
Visual	(N)	The model does not have visualization capabilities
	(2-D)	2-dimension visualization available
	(3-D)	3-dimension visualization available
Validation	(C)	Validation against codes
	(FD)	Validation against fire drills or other people movement experiments/trials
	(PE)	Validation against literature on past experiments (flow rates, etc.)
	(OM)	Validation against other models
	(3P)	Third party validation
	(N)	No validation work could be found regarding the model

For the special features, except route choice, the model is labeled as either having this capability or not having this capability. If the model has this capability, a “Y” for yes is placed in Table A1-3. If not, an “N” for no is placed in Table A1-3. For route choice of the occupants, the various options provided to the user for simulating occupant route choice are described in Table A1-3.

Table A1-2: Main Features of Reviewed Egress Models (Kuligowsky et al., 2010)

<i>Model</i>	<i>Available to public</i>	<i>Modeling Method</i>	<i>Purpose</i>	<i>Grid/ Structure</i>	<i>Perspective of M/O</i>	<i>Behavior<sup>a</sup></i>	<i>Movement<sup>a</sup></i>	<i>Fire data</i>	<i>CAD</i>	<i>Visual</i>	<i>Valid</i>
EVACNET4	Y	M-O	1	C	G	N	UC	N	N	N	FD
WAYOUT	Y	M	5	C	G	N	D	N	N	2-D	FD
STEPS <sup>c</sup>	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	C,FD,PE
PEDROUTE	Y	PB	3	C	G	I	D	N	Y	2,3-D	N
Simulex <sup>b</sup>	Y	PB	1	Co.	I	I	ID	N	Y	2-D	FD,PE, 3P
GridFlow	Y	PB	1	Co.	I	I	D	N	Y	2,3-D	FD, PE
FDS+Evac <sup>c</sup>	Y	PB	1	Co.	I	I, C, P	ID	Y3	N/Y	2,3-D	FD,PE,OM
Pathfinder 2009 <sup>c</sup>	Y	PB	1	Co.	I/G	I	D,ID	N	Y	2,3-D	C,FD,PE,OM
SimWalk <sup>c</sup>	Y	PB	1,3	Co.	I	C, P	P	N	Y	2,3-D	FD,PE,3P
PEDFLOW <sup>c</sup>	Y	B	1	Co.	I	C, P	ID	Y2	Y	2,3-D	PE
PedGo <sup>c</sup>	Y,N1	PB/B	1	F	I/I,G	I/C, P	P,E (CA), C	Y2	Y	2,3-D	FD,PE,OM,3P
ASERJ <sup>c</sup>	Y	B-RA	1	Co.	I	C, P	ID	Y1,2	Y	2,3-D	FD, PE
BldEXO <sup>b</sup>	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	FD,PE,OM,3P
Legion <sup>c</sup>	Y,N1	B	1	Co.	I	AI, P	ID, C	Y1	Y	2,3-D	C,FD,PE,3P
SpaceSensor <sup>c</sup>	Y	B	3	Co.	I	C, P	C, Ac_K	N	Y	2,3-D	FD,OM
EPT <sup>c</sup>	Y,N1	B	1	F	I	AI	UC,C	Y2	Y	2,3-D	FD
Myriad II <sup>c</sup>	Y, N1	B	1	C, F, Co.	I	AI	D, UC, IP, Ac_K	Y1	Y	2,3-D	PE, 3P
MassMotion <sup>c</sup>	Y, N1	B	1	Co.	I/I,G	AI,P	C	N	Y	2,3-D	C,FD,PE,OM
PathFinder	N1	M	1	F	I/G	N	D	N	Y	2-D	N
ALLSAFE	N1	PB	5	C	G	I	Un_F	Y1,2	N	2-D	OM
CRISP	N1	B-RA	1	F	I	C, P	E,D	Y3	Y	2,3-D	FD
EGRESS 2002	N1	B	1	F	I	C, P	P,D (CA)	Y2	N	2-D	FD
SGEM <sup>c</sup>	N1	PB	1	Co.	I	I	D	N	Y	2-D	FD,OM
EXIT89 <sup>c</sup>	N2	PB	1	C	I	I/C, P	D	Y1	N	N	FD,3P
MASSEgress <sup>b</sup>	N2	B	1	Co.	I	C, AI	C	N	Y	2,3-D	PE,OM
EvacuatioNZ <sup>c</sup>	N2	B	1	C	I/I,G	I, C, P	D, UC	Y2	Y	2-D	FD, PE,OM

<sup>a</sup>Only the underlying methods used by the algorithm are listed. In some instances users can define other options

<sup>b</sup>Model developers/NIST provided an update on the model's development in Spring 2009.

<sup>c</sup>Model developers/NIST provided an update on the model's development in Fall 2010.

Table A1-3: Special Features of Reviewed Egress Models (Kuligowsky et al., 2010)

<i>Model</i>	<i>Counter-flow</i>	<i>Exit Block</i>	<i>Fire Conditions</i>	<i>Toxicity</i>	<i>Groups</i>	<i>Disabled / slower</i>	<i>Delays/pre-evacuation</i>	<i>Elevator use</i>	<i>Route choice</i>
EVACNET4	N	N	N	N	N	N	N	Y	Optimal routes
WAYOUT	N	N	N	N	N	N	Y	N	1 route, flows merge
STEPS <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	Y	Conditional
PEDROUTE	N	N	N	N	Y	Y	Y	N	Shortest, optimal, or signage
Simulex <sup>b</sup>	Y	Y	N	N	Y	Y	Y	N	Shortest or altered distance map
GridFlow	Y	Y	N	Y	N	Y	Y	N	Shortest, random, user-def.
FDS+Evac <sup>c</sup>	Y	Y	Y	Y	N	Y	Y	N	Optimal, conditional
Pathfinder 2009 <sup>c</sup>	Y	Y	N	N	Y	Y	Y	N	Shortest, user-def.
SimWalk <sup>c</sup>	Y	N	N	N	Y	Y	Y	Y	Shortest
PEDFLOW <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	Y	Shortest, conditional
PedGo <sup>c</sup>	Y	Y	Y	N	Y	Y	Y	N	Probabilistic/conditional, user-def.
ASER1 <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	N	Shortest, user-def., conditional
BldEXO <sup>b</sup>	Y	Y	Y	Y	Y	Y	Y	N	Various
Legion <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	Y	Conditional
SpaceSensor <sup>c</sup>	N	Y	N	N	N	N	N	Y	Conditional – visual perception
EPT <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	Y	Shortest, conditional
Myriad II <sup>c</sup>	Y	Y	Y	Y	Y	Y	Y	Y	Various
MassMotion <sup>c</sup>	Y	Y	Y	N	Y	Y	Y	Y	Shortest, conditional
PathFinder	N	N	N	N	N	N	N	N	User's choice – 2 choices
ALLSAFE	N	N	Y	N	Y	N	Y	N	1-Choice
CRISP	Y	Y	Y	Y	Y	Y	Y	N	Shortest, user-def., conditional
EGRESS 2002	Y	Y	Y	Y	Y	Y	Y	N	Conditional
SGEM <sup>c</sup>	Y	Y	N	N	N	Y	Y	Y	Shortest time, conditional
EXIT89 <sup>c</sup>	Y	Y	Y	Y	N	Y	Y	N	Shortest distance, user-def.
MASSEgress <sup>b</sup>	Y	Y	N	N	Y	Y	Y	N	Conditional – visual perception
EvacuatioNZ <sup>c</sup>	N	Y	Y	N	Y	Y	Y	N	Various

<sup>b</sup>Model developers/NIST provided an update on the model's development in Spring 2009.

<sup>c</sup>Model developers/NIST provided an update on the model's development in Fall 2010.



## Annex 2- Pathfinder 2015 and Pathfinder 2017 Main and Special Features

The main and special features of 2015 and 2017 versions of *Pathfinder* simulation tool can be found in Table A2-1 (using the abbreviations in Table A1-1 from Annex 1). It is important to mention that data in Table A1-2 and Table A1-3 (referring to Pathfinder 2009) are no longer valid to *Pathfinder* 2015 and to *Pathfinder* 2017.

Table A2-1: *Pathfinder* 2015 and *Pathfinder* 2017 Features (Thunderhead Engineering, 2015, 2017)

Main Features											
Model	Available to public	Modeling Method	Purpose	Grid/ Structure	Perspective of M/O	Behavior	Movement	Fire Data	CAD	Visual	Valid
<i>Pathfinder</i> 2015	Y	PB	1	Co	I/G	I	D/ID	Y	Y	2, 3-D	C, FD, PE, OM
<i>Pathfinder</i> 2017	Y	PB	1	Co	I/G	I	D/ID	Y	Y	2, 3-D	C, FD, PE, OM
Special Features											
Model	Counter Flow	Exit Block	Fire Conditions	Toxicity	Groups	Disabled/ Slower	Delays/Pre-evacuation	Elevator Use	Route Choice	Refuge Areas	Assistance Teams
<i>Pathfinder</i> 2015	Y	Y	Y	N	N	N/Y	Y	Y	Shortest, User-def	N	N
<i>Pathfinder</i> 2017	Y	Y	Y	N	N	Y/Y	Y	Y	Shortest, User-def	Y	Y



## Annex 3- Validation Case Specific Features

Table A3-1: *Joalpe* Validation Case Occupants' Profile Features

Characteristics				Movement	
Profile	Speed [m/s]	Shoulder Width [cm]	Height [m]	Use Stairs	Ignore One-way Door Restrictions
Default	1,25	45,58	1,8288	Yes	Yes

Table A3-2: *Joalpe* Validation Case Stairs' Characteristics

Stairs	Width [cm]	Length [m]	Riser [cm]	Tread [cm]
Stair1_1	121,492	1,80	17,78	27,94
Stair1_2	121,492	1.80	17,78	27,94

Table A3-3: *Joalpe* Validation Case Exit Doors' Features

Door Type	Width [cm]	State (t[s])	One Way Door	Quantity
Main Door	220	AO	No	1
Wood Unit Main Door	90	AO	No	1
Emergency Door	90	AO	Yes	7

Table A3-4: *Joalpe* Occupants Distribution (for All Validation Cases)

Drill	Occupants	Workers	Non-workers/ Visitors	PRM	Plastic Unit	Wood Unit	PU First Floor
N°1	29	29	0	0	16	13	0
N°2	54	52	2	0	36	13	5
N°3	40	40	0	0	29	11	3
N°4	68	62	6	0	52	16	6
N°5	16	16	0	0	16	0	2
N°6	62	60	2	0	41	6	13

### First Validation Case

Table A3-5: *Joalpe* Drill n°1 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]
Exit Wood Unit	ED7 and WU_MainDoor	86,6
Exit Plastic Unit First Floor	PU_MainDoor	86,6
Go to Any Exit	Any Door	86,6

### Second Validation Case

Table A3-6: *Joalpe* Drill n°2 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]	Go to Point	Wait [s]	Go to Point	Wait [s]
Exit Wood Unit	ED7 and WU_MainDoor	148,8	Point 1	-	-	124,2
Exit Plastic Unit First Floor	PU_MainDoor	148,8	Point 1	-	-	124,2
Go to Any Exit	Any Door	148,8	Point 1	-	-	124,2
Injured	PU_MainDoor	148,8	Point 1	72	-	124,2
Injured Help	PU_MainDoor	148,8	Point 2	72	Point 1	124,2

### Third Validation Case

Drill n°3 occurred, without workers notice, on october 13<sup>th</sup>, 2014, in a general shift by 08h15m and at that time 40 occupants were in the building (all workers without mobility impairments). According to this drill report, the occupants recognized the emergency 150,6 s after the drill beginning, then they selected an exit door and went to gathering point (“Point 1”) where a count of the occupants was made (with unknown duration) and then they were authorized to leave the perimeter. This drill worked as an awareness raising action so there were no affected zones or blocked doors. The following flowchart (Figure A3-1) and Table A3-7 sum up this drill behavior.

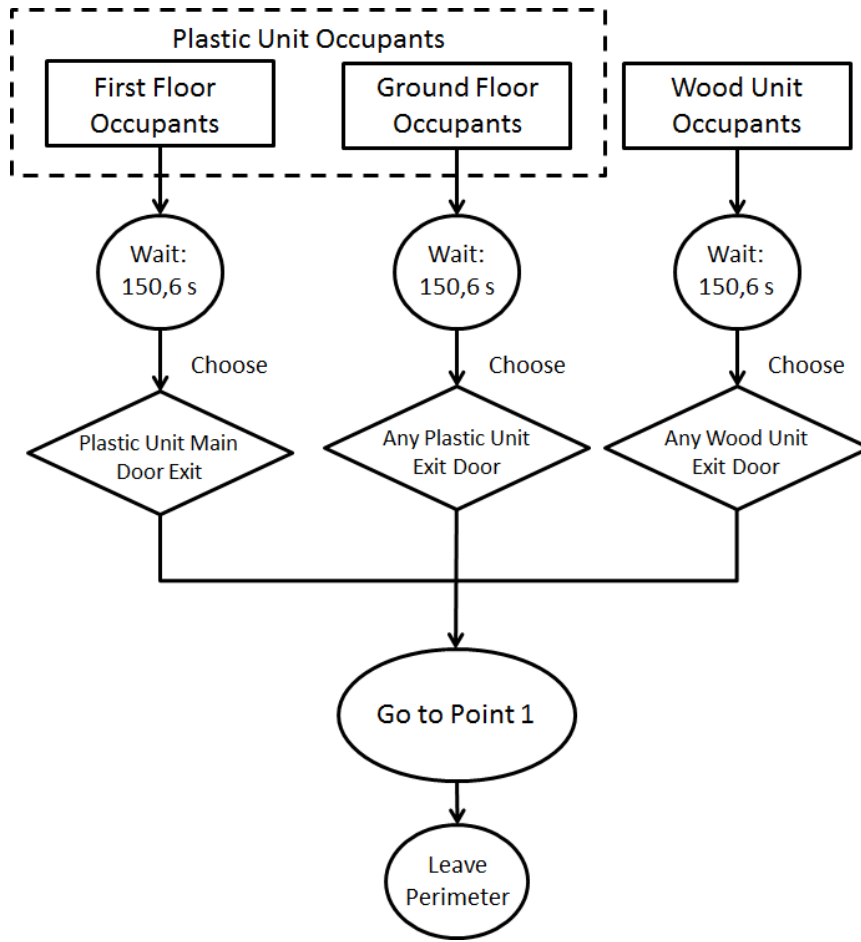


Figure A3-1: Joalpe Drill n°3 Occupants' Behavior

Table A3-7: Joalpe Drill n°3 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]	Go to Point
Exit Wood Unit	ED7 and WU_MainDoor	150,6	Point 1
Exit Plastic Unit First Floor	PU_MainDoor	150,6	Point 1
Go to Any Exit	Any Door	150,6	Point 1

With the parameters regarding this validation case and the drill defined before, the geometry obtained in the simulation tool is that of Figure 23, in Chapter 3.

#### Fourth Validation Case

Drill n°4 occurred, without workers notice, on october 27<sup>th</sup>, 2015, in a general shift by 10h45m and at this time 68 occupants were in the building (62 workers, 2 observers and 4 external workers all without mobility impairments). According to Joalpe report, the Drill n°4

occupant's recognized the emergency 91,2 s after the drill start, then they selected an exit door and went to gathering point ("Point 1") where a count of the occupants was made (lasted 168 s) and then they were authorized to leave the perimeter. In this drill an injured existed in the first floor (at "Point 2") and two occupants recognized the injured 375,2 s after the drill start and helped the injured to go to the meeting point ("Point 1"). This drill worked as a fire in the computer room (in the Plastic Unit) where there were no affected zones or blocked doors. The following flowchart (Figure A3-2) and Table A3-8 sum up this drill behavior.

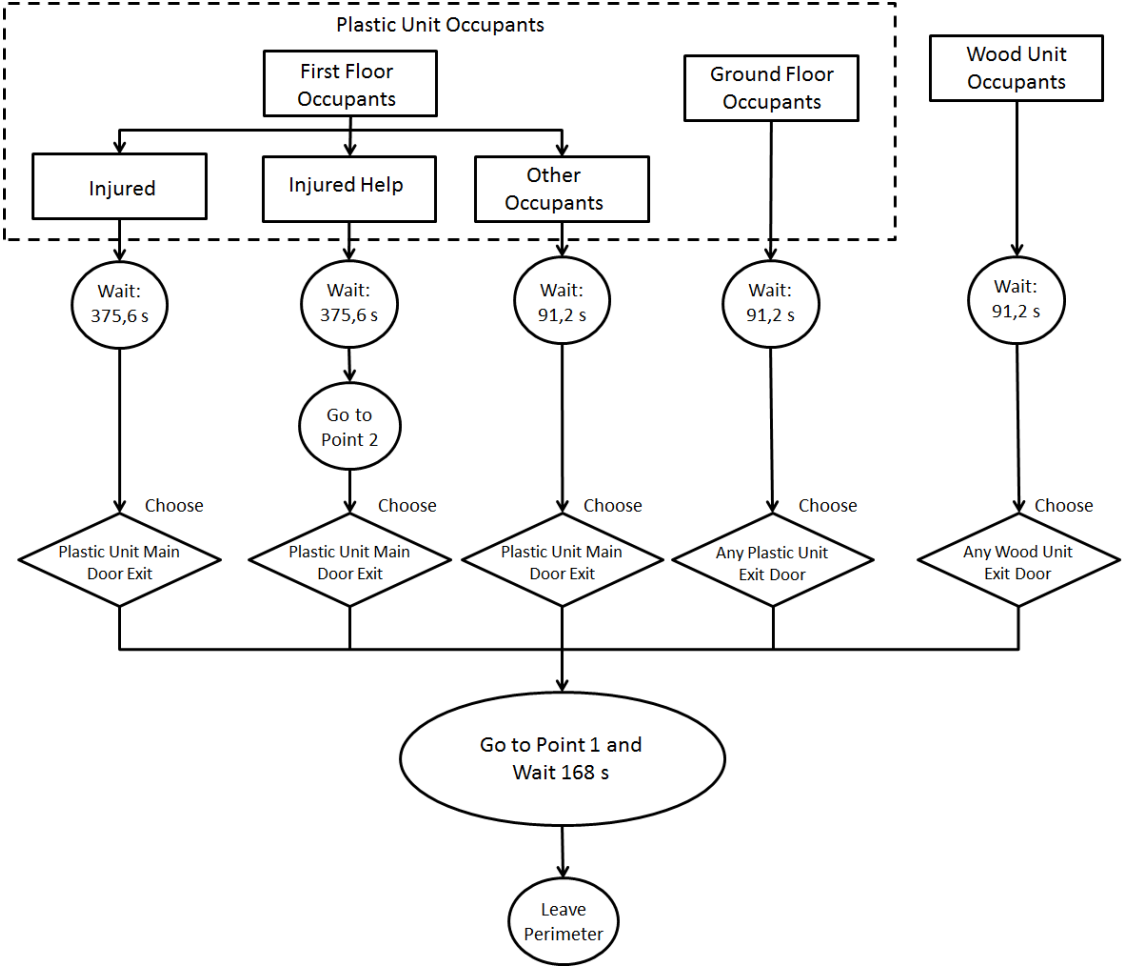


Figure A3-2: Joalpe Drill n°4 Occupants' Behavior

Table A3-8: *Joalpe* Drill n°4 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]	Go to Point	Go to Point	Wait [s]
Exit Wood Unit	ED7 and WU_MainDoor	91,2	Point 1	-	168,0
Exit Plastic Unit First Floor	PU_MainDoor	91,2	Point 1	-	168,0
Go to Any Exit	Any Door	91,2	Point 1	-	168,0
Injured	PU_MainDoor	375,6	Point 1	-	168,0
Injured Help	PU_MainDoor	375,6	Point 2	Point 1	168,0

With the parameters regarding this validation case and the drill defined before, the geometry obtained in the simulation tool is that of Figure A3-3.

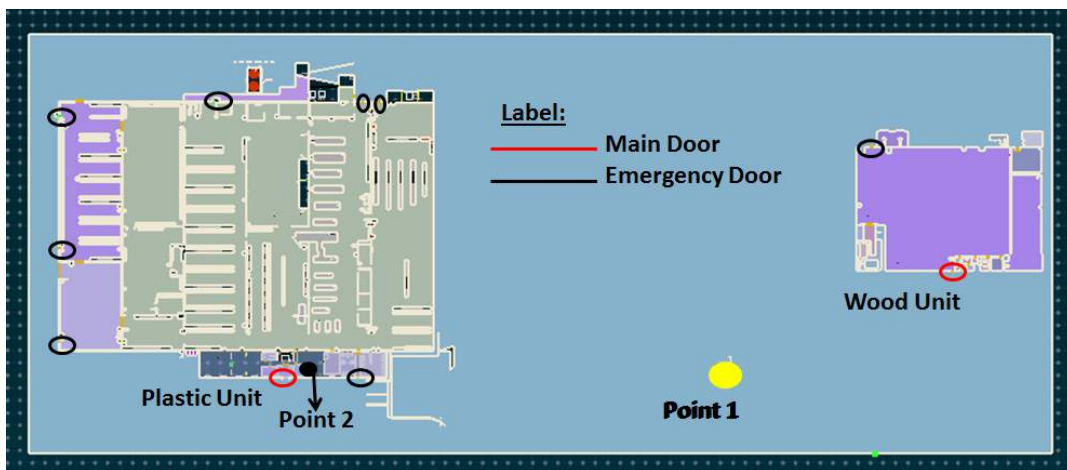


Figure A3-3: Drill n°4 Pathfinder Geometry Mesh

### Fifth Validation Case

Drill n°5 occurred, without workers notice, on march 24<sup>th</sup>, 2016, in a general shift by 18h15m and at this time 16 occupants were in the building (all workers without mobility impairments). According to *Joalpe* report, the Drill n°5 occupant's recognized the emergency 80,4 s after the drill start, then they selected an exit door and went to gathering point ("Point 1") where a count of the occupants was made (lasted 46,2 s) and then they were authorized to leave the perimeter. This drill worked as an awareness raising action so there were no affected zones or blocked doors. The flowchart of Figure A3-4 and the Table A3-9 sum up this drill behavior.

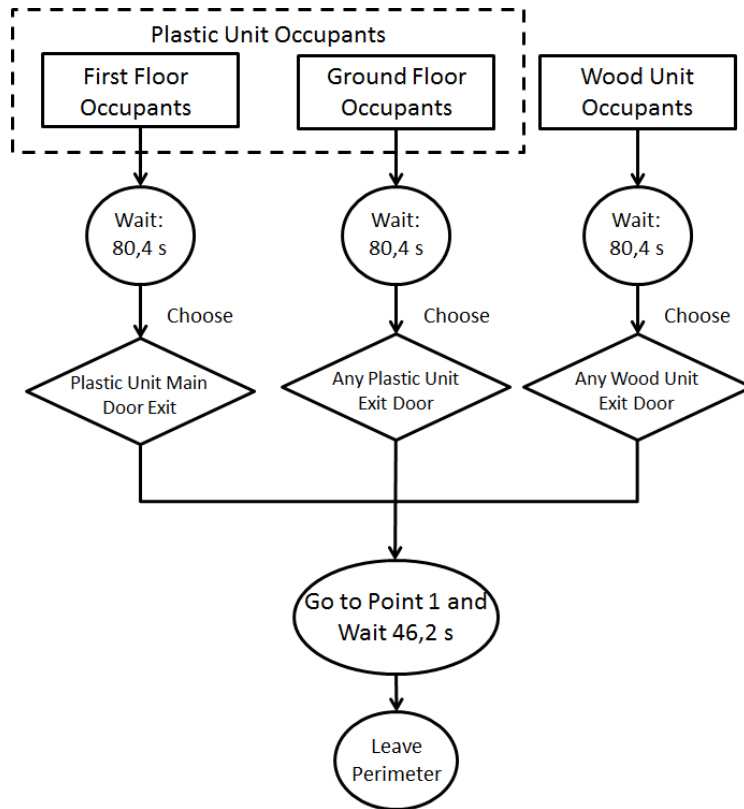


Figure A3-4: Joalpe Drill n°5 Occupants' Behavior

Table A3-9: Joalpe Drill n°5 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]	Go to Point	Wait [s]
Exit Wood Unit	ED7 and WU_Main_Door	80,4	Point 1	202,5
Exit Plastic Unit First Floor	PU_MainDoor	80,4	Point 1	202,5
Go to Any Exit	Any Door	80,4	Point 1	202,5

With the parameters regarding this validation case and the drill defined before, the geometry obtained in the simulation tool is that of Figure 23, in Chapter 3.

### Sixth Validation Case

Having been granted an authorization to attend a drill to be held in December, it was possible to make a different assessment from the previously made, that is, the early simulation of an evacuation exercise scenario that would later be put into practice (without previous notice of company's employees).

Thus, *Joalpe* proposed that we simulate a fire scenario in the area of manufactured products that would block one of the exits of this area of the plastic unit. In Figure A3-5, we can observe the geometry obtained in the program:

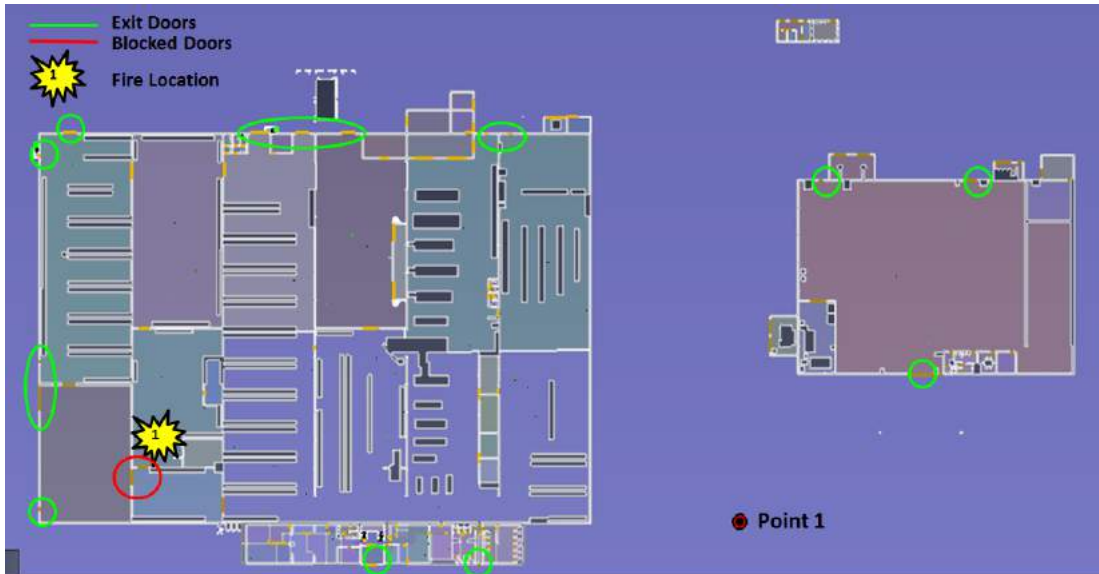


Figure A3-5: Drill n°6 Pathfinder Geometry Mesh

In this scenario the behavior of the occupants would be described as shown in Figure A3-6 and Table A3-10, and there would be no injured or disabled people at the building.

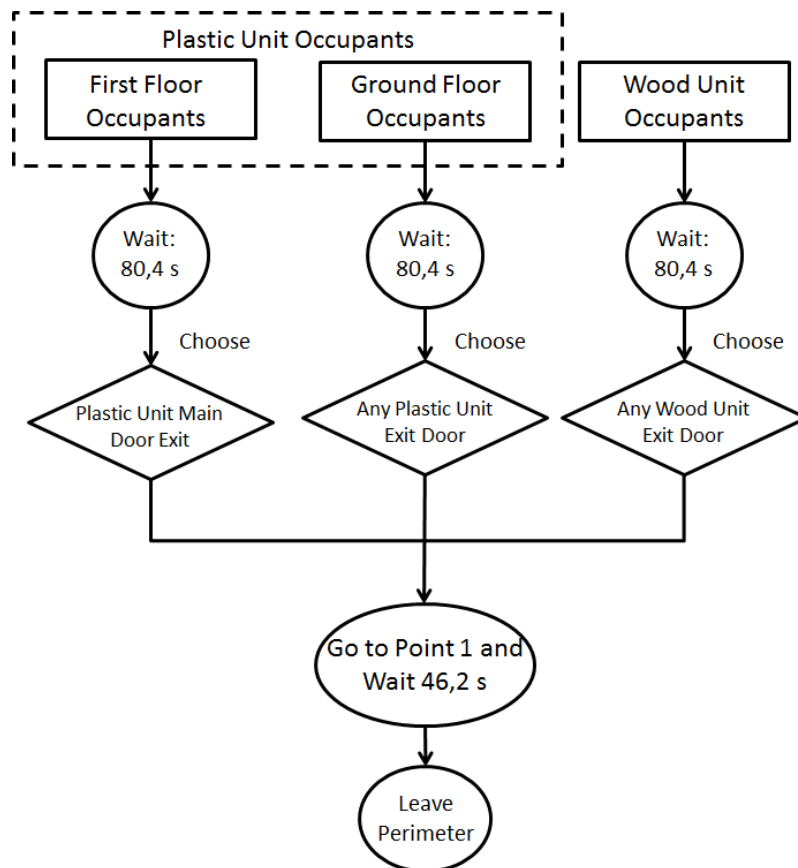


Figure A3-6: *Joalpe* Drill n°6 Occupants' Behavior

Table A3-10: *Jolpe* Drill n°6 Occupants Behavior

Behaviors	Exits Allowed	Initial Delay [s]	Go to Point
Exit Wood Unit	Any Door	0,00	Point 1
Exit Plastic Unit First Floor	Any Door	0,00	Point 1
Go to Any Exit	Any Door	0,00	Point 1

## Annex 4- Terminal A Floor Plans and 3D Views

Table A4-1: Terminal A Room Schedule

Number	Terminal Area	Room Type	Name	Level
1	Restrict	Baggage Handling	OF Baggage Handling	Ground Floor
2	Public	Baggage Handling	OF Baggage	Ground Floor
3	Restrict	Baggage Handling	Baggage Handling	Ground Floor
4	Restrict	Restaurant/Food Store	Pastry Shop 1	Ground Floor
5	Restrict	Services/Information	AC1 Counter	Ground Floor
6	Restrict	Services/Information	AC2 Counter	Ground Floor
7	Restrict	Services/Information	Information Counter	Ground Floor
8	Restrict	Services/Information	PRM Services Counter	Ground Floor
9	Restrict	Services/Information	Tourism Counter	Ground Floor
10	Restrict	Staff Offices	PRM Services Office	Ground Floor
11	Restrict	Staff Offices	Information Office	Ground Floor
12	Restrict	Staff Offices	AC2 Office	Ground Floor
13	Restrict	Staff Offices	AC1 Office	Ground Floor
14	Restrict	Staff Offices	Hallway 1	Ground Floor
15	Restrict	Staff Offices	Staff Room 1	Ground Floor
16	Restrict	Baggage Handling	Baggage Handling	Ground Floor
17	Restrict	Check-in	Check-in Counters	Ground Floor
18	Restrict	Staff Offices	Baggage Handling Office	Ground Floor
19	Restrict	Staff Offices	Terminal A Handler Office	Ground Floor
20	Restrict	Staff Offices	Terminal A Handler Staff Closet	Ground Floor
21	Public	Sanitary	Women WC	Ground Floor
22	Public	Sanitary	Men WC	Ground Floor
23	Public	Sanitary	PRM WC	Ground Floor
24	Boarding	Sanitary	Women WC 1	Ground Floor
25	Boarding	Sanitary	Men WC 1	Ground Floor
26	Boarding	Sanitary	PRM WC 1	Ground Floor
27	Public	Public Area	WC Hall	Ground Floor

28	Boarding	Sanitary	WC Hall	Ground Floor
29	Restrict	Sanitary	Women WC	Ground Floor
30	Restrict	Sanitary	Men WC	Ground Floor
31	Restrict	Staff Offices	Police, Terminal Handler Staff and PRM Services	Ground Floor
32	Restrict	Staff Warehouse	PRM Services Warehouse	Ground Floor
33	Restrict	Staff Offices	PRM Staff Closet	Ground Floor
34	Restrict	Staff Offices	Handler Office	Ground Floor
35	Restrict	Staff Offices	Handler Staff Closet 1	Ground Floor
36	Restrict	Staff Offices	Security Staff Office	Ground Floor
37	Restrict	Police	Police Office 3	Ground Floor
38	Restrict	Police	Police Office 2	Ground Floor
39	Restrict	Police	Police Office 1	Ground Floor
40	Restrict	Staff Offices	Security Staff Closet	Ground Floor
41	Restrict	Staff Offices	Staff Closet	Ground Floor
42	FBS	Staff Offices	FBS Office 1	Ground Floor
43	FBS	Staff Offices	FBS Office 2	Ground Floor
44	FBS	Staff Offices	FBS Office Hallway	Ground Floor
45	Boarding	Services/Information	Bank	Ground Floor
46	FBS	Sanitary	Men WC	Ground Floor
47	FBS	Sanitary	PRM WC	Ground Floor
48	FBS	Sanitary	Women WC	Ground Floor
49	Boarding	Sanitary	Men WC 2	Ground Floor
50	Boarding	Sanitary	PRM WC 2	Ground Floor
51	Boarding	Sanitary	Women WC 2	Ground Floor
52	FBS	Waiting Area	FBS Boarding Area	Ground Floor
53	Public	Waiting Area	WPA	Ground Floor
54	Public/Boarding	Security	Security Check-Point	Ground Floor
55	Boarding	Stores	Store 1	Ground Floor
56	Boarding	Stores	Duty-Free Store 1	Ground Floor
57	Boarding	Gates	Gates	Ground Floor

58	Boarding	Stores	Store 2	Ground Floor
59	Boarding	Restaurant/Food Store	Pastry Shop 2	Ground Floor
60	Boarding	Stores	Duty-Free Store 2	Ground Floor
61	Boarding	Security	FBS Security Check-Point	Ground Floor
62	Restrict	Restaurant/Food Store	Restaurant	Ground Floor
63	Restrict	Staff Offices	Restaurant Office	Ground Floor
64	Boarding	Stores	Store 3	Ground Floor
65	Boarding	Stores	Store 4	Ground Floor
66	Restrict	Staff Offices	Restaurant Staff Closet	Ground Floor
67	Restrict	Staff Warehouse	Stores' Warehouse	Ground Floor
68	Restrict	Staff Offices	Cleaning Closet	Ground Floor
69	Boarding	Waiting Area	BWA	Ground Floor
70	Boarding	Restrict Area	Dining Area	Ground Floor
71	Exterior	Services/Information	Post Card Office	Ground Floor
72	Exterior	Services/Information	Rent-A-Car Store	Ground Floor
73	Restrict	Staff Offices	Management Office 1	First Floor
74	Restrict	Staff Offices	Management Office 2	First Floor
75	Restrict	Staff Offices	Management Offices	First Floor

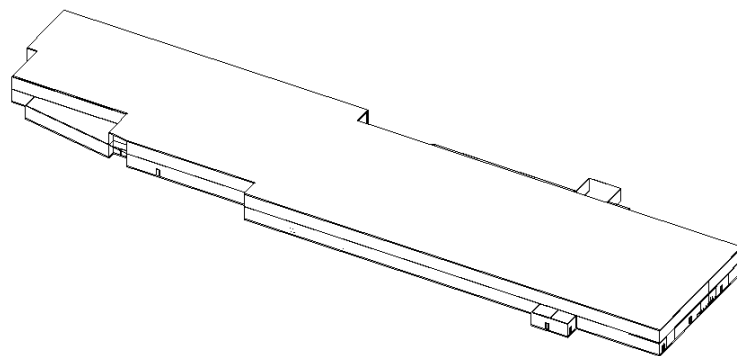


Figure A4-1: Terminal A 3D Front View

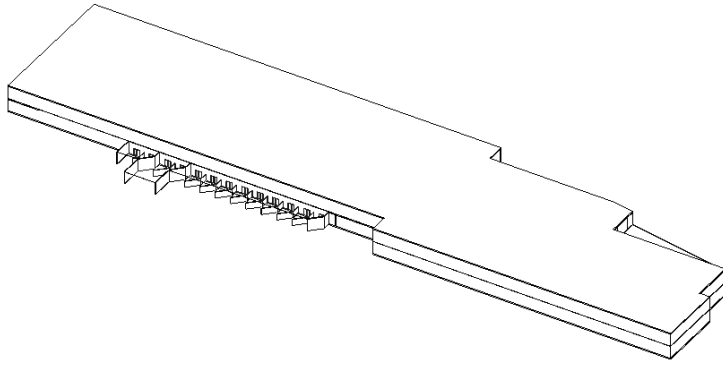


Figure A4-2: Terminal A 3D Back View

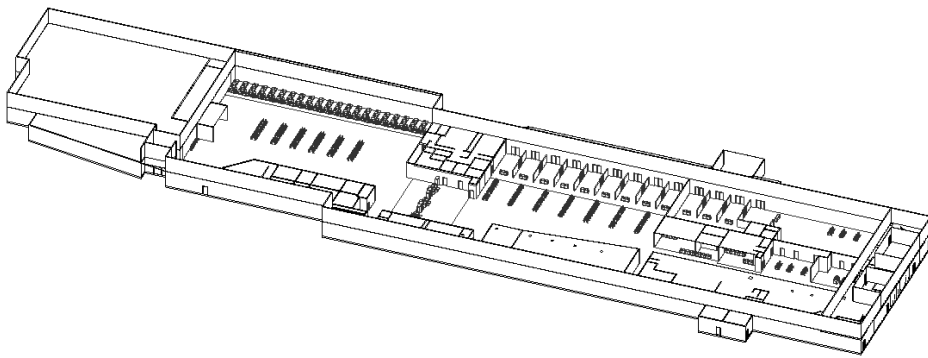


Figure A4-3: Terminal A 3D Front Interior View (without Roof)

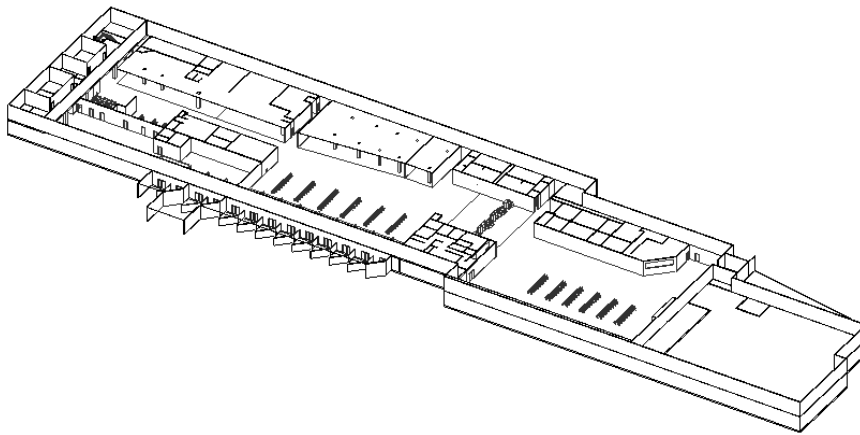


Figure A4-4: Terminal A 3D Back Interior View (without Roof)

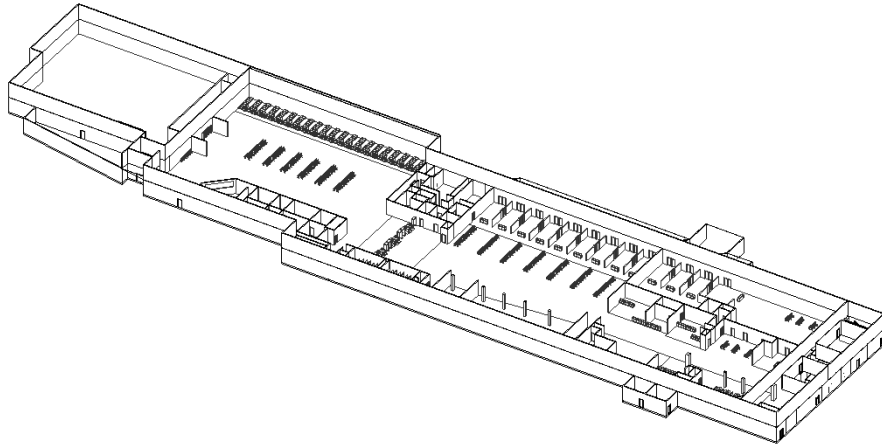


Figure A4-5: Terminal A 3D Front Interior View (without Roof and Ceilings)

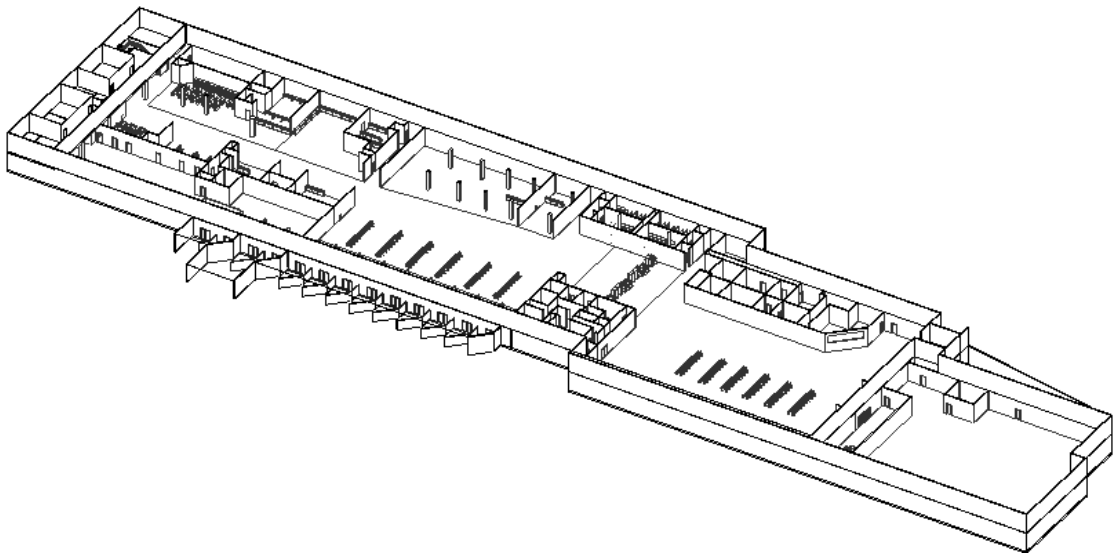


Figure A4-6: Terminal A 3D Back Interior View (without Roof and Ceilings)

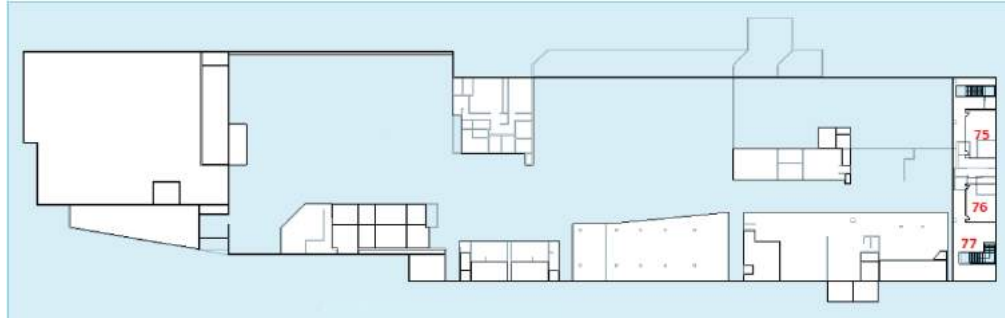


Figure A4-7: Terminal A First Floor plans

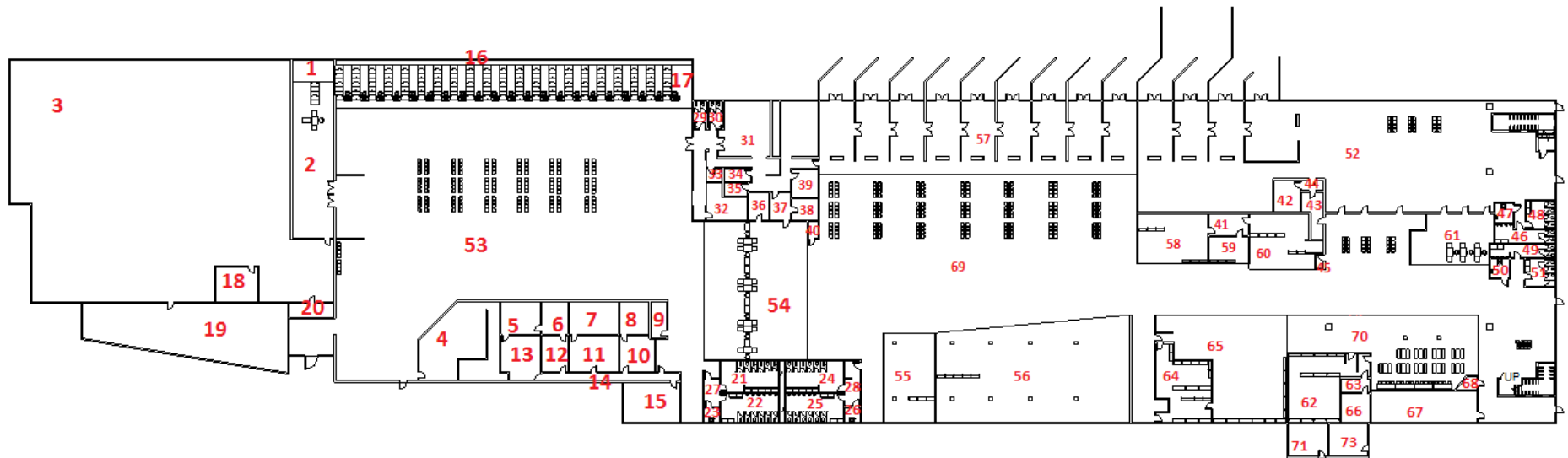


Figure A4-8: Terminal A Ground Floor plan

## Annex 5- Terminal A and Simulation General Parameters

Table A5-1: Terminal A Occupants Profile

Characteristics			Movement		
Profile	Speed [m/s]	Shoulder Width [cm]	Height [m]	Use Stairs	Ignore One-way Door Restrictions
Default	1,25	45,58	1,8288	Yes	No
Staff	1,25	45,58	1,8288	Yes	Yes
Elder	0,45	45,58	1,8288	Yes	No
Wheelchair	0,36	90,0	1,3500	No	No
Crutches	0,94	90,0	1,8288	Yes	No
Hiker	0,57	85,0	1,8288	No	No
Cane	0,81	75,0	1,8288	Yes	No

Table A5-2: Terminal A Doors Characteristics

Door Type	Nomenclature	Width [cm]	Height [cm]	State (t[s])	One Way Door
Main Door	MainDoor	120,0	203,2	AO	No
Emergency Door	EDx	95,0	203,2	AO	Yes
Exit Door	Exit_Room	95,0	203,2	AO	No
Gates	Gatex	120,0	203,2	AC	Yes
Interior Restrict Door	Doorx	90,0	203,2	AC, t=1	Yes
Interior Non Restrict Door	Doorx	95,0	203,2	AO	No
Gate Communication Door	Gate_AB	120,0	203,2	AC, t=1	No
BWA to FBS Door	BWA_FBSx	95,0	203,2	AC, t=1	Yes
WC Door	WCx	95,0	203,2	AO	No
PRM Emergency Door	PRM_EDx	100,0	203,2	AO	Yes

Table A5-3: Terminal A Stairs Characteristics

Stairs	Width [cm]	Length [m]	Riser [cm]	Tread [cm]	Number of Risers
Stair1_1	121,492	1,91441	17,78	27,94	5
Stair1_2	121,492	2,52683	17,78	27,94	5
Stair1_3	121,492	2,01659	17,78	27,94	5
Stair1_4	121,492	2,03259	17,78	27,94	7
Stair2_1	121,492	2,34593	17,78	27,94	7
Stair2_2	121,492	1,58126	17,78	27,94	5
Stair2_3	121,492	1,65474	17,78	27,94	5
Stair2_4	121,492	2,06521	17,78	27,94	5

# Annex 6- Terminal A Specific Parameters for Each Simulation

Table A6-1: Modeling Parameters for Each Simulation

		Simulation 1	Simulation 1A	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7
Occupants	Profile Distribution	Table 20	Only "default" and "staff" from Table 20	Table 20	Table 20	Table 20	Table 20	Table 20	Table 20
	Profile Characteristics	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33	Figure 32 and 33
	Initial Position	Defined	Simulation 1	Simulation 1	Simulation 1	Simulation 1	Simulation 1	Simulation 1	Simulation 1
Exits and Stairs		Figure 34 to 38	Figure 34 to 38	Figure 34 to 38	Figure 34 to 38 and Figure	Figure 34 to 38 and Figure	Figure 34 to 38 and Figure	Figure 34 to 38 and Figure	Figure 34 to 38 and Figure
Incident	Type	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified	Spontaneous/ Unspecified
	Injuries/ Casualties	None	None	None	None	None	None	None	None
	Recognition	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Others	Destroyed/ Blocked Areas	None	None	None	None	None	None	None	None
	Refuge Areas	No	No	No	No	No	No	Yes	Yes
	Assistance Teams	No	No	No	No	No	No	No	Yes

Door/Egress Route Restrictions	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
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Table A6-1: Terminal A Number of Exit Doors for Each Simulation

Door Type	Quantity						
	Sim 1 and 1A	Sim 2	Sim 3	Sim 4	Sim 5	Sim 6	Sim 7
Main Door	1	1	1	1	1	1	1
Emergency Door	5	22	22	22	22	22	22
Exit Door	2	2	2	2	3	2	2
PRM Door	-	-	7	7*	7*	-	-
Total	8	25	32	32	33	25	25
* With a Separation Wall							

Table A6-2: Second Simulation Behaviors

Behavior	Exits Allowed	Behavior	Exits Allowed
PWA	MainDoor, ED1,ED6, ED9, ED10, ED11	Restrict	EDr1, EDr2
Hallway and SR	EDhall, EDsroom	Restrict2	ED2,ED3, ED4, ED5
Check In (Staff)	ED9	Exterior	EDpc
Baggage	EDr3, EDr4, EDr,EDr5	Exterior2	EDrac
BWA	ED7, ED8, ED12, ED13, EDstore3	FBS	ED4, ED5
BWA2	ED2, ED3	Store1	EDstore1
DutyFree1	EDdfree	Store 3	Estore3

Table A6-3: Third and Fourth Simulation Behaviors

Behavior	Exits Allowed	Behavior	Exits Allowed
PWA	MainDoor, ED1,ED6, ED9, ED10, ED11	PRM_BWA2	BWA2 exits, PRM_ED5
PRM_PWA	PWA exits, PRM_ED1, PRM_ED2, PRM_ED7	DutyFree1	EDdfree
Check In (Staff)	ED9	Exterior	EDpc
Baggage	EDr3, EDr4, EDr,EDr5	Exterior2	EDrac
BWA	ED7, ED8, ED12, ED13, EDstore3	FBS	ED4, ED5
PRM_BWA	BWA exits, PRM_ED3, PRM_ED4	PRM_FBS	FBS exits, PRM_ED6
BWA2	ED2, ED3	Hallway and SR	EDhall, EDsroom
Store1	EDstore1	Restrict	EDr1, EDr2
Store 3	Estore3	Restrict2	ED2,ED3, ED4, ED5

Table A6-4: Fifth Simulation Ramps' Characteristics

Ramps	Width [cm]	Length [m]	Ramps	Width [cm]	Length [m]
Ramp1_1	121,92	3,25369	Ramp2_1	121,92	2,92993
Ramp1_2	121,92	3,16228	Ramp2_2	121,92	3,16228
Ramp1_3	121,92	2,72734	Ramp2_3	121,92	2,8638
Ramp1_4	121,92	2,32072	Ramp2_4	121,92	2,60381

Table A6-5: Fifth Simulation Behaviors

Behavior	Exits Allowed	Behavior	Exits Allowed
PWA	MainDoor, ED1,ED6, ED9, ED10, ED11	PRM_BWA2	BWA2 exits, PRM_ED5
PRM_PWA	PWA exits, PRM_ED1, PRM_ED2, PRM_ED7	DutyFree1	EDdfree
Check In (Staff)	ED9	Exterior	EDpc
Baggage	EDr3, EDr4, EDr,EDr5	Exterior2	EDrac
BWA	ED7, ED8, ED12, ED13, EDstore3	FBS	ED4, ED5
PRM_BWA	BWA exits, PRM_ED3, PRM_ED4	PRM_FBS	FBS exits, PRM_ED6
BWA2	ED2, ED3	Hallway and SR	EDhall, EDsroom
Store1	EDstore1	Restrict	EDr1, EDr2
Store 3	EDstore3	Restrict2	EDramp

Table A6-6: Sixth Simulation Behaviors

Behavior	Exits/Refuge Areas Allowed	Behavior	Exits Allowed
PWA	MainDoor, ED1,ED6, ED9, ED10, ED11	PRM_BWA2	BWA Refuge Areas
PRM_PWA	PRM Refuge Areas	DutyFree1	EDdfree
Check In (Staff)	ED9	Exterior	EDpc
Baggage	EDr3, EDr4, EDr,EDr5	Exterior2	EDrac
BWA	ED7, ED8, ED12, ED13, EDstore3	FBS	ED4, ED5
PRM_BWA	BWA Refuge Areas	PRM_FBS	FBS Refuge Area
BWA2	ED2, ED3	Hallway and SR	EDhall, EDsroom
Store1	EDstore1	Restrict	EDr1, EDr2
Store 3	Estore3	Restrict2	ED2,ED3, ED4, ED5

Table A6-6: Seventh Simulation Behaviors

Behavior	Wait for Assistance Team	Exits/Refuge Areas Allowed	Behavior	Wait for Assistance Team	Exits Allowed
PWA	-	MainDoor, ED1,ED6, ED9, ED10, ED11	PRM_BWA2	BWA Teams	BWA Refuge Areas
PRM_PWA	PWA Teams	PRM Refuge Areas	DutyFree1	-	EDdfree
Check In (Staff)	-	ED9	Exterior	-	EDpc
Baggage	-	EDr3, EDr4, EDr,EDr5	Exterior2	-	EDrac
BWA	-	ED7, ED8, ED12, ED13, EDstore3	FBS	-	ED4, ED5
PRM_BWA	BWA Teams	BWA Refuge Areas	PRM_FBS	FBS Teams	FBS Refuge Area
BWA2	-	ED2, ED3	Hallway and SR	-	EDhall, EDsroom
Store1	-	EDstore1	Restrict	-	EDr1, EDr2
Store 3	-	Estore3	Restrict2	-	ED2,ED3, ED4, ED5



## Annex 7- Compilation of Terminal A *Pathfinder* Simulation Results

This annex compiles all the Terminal A *Pathfinder* simulation results for the key exit doors from all simulation scenarios (Chapter 4) for its detailed analyze and discussion. Table A7-1 shows these results where it is indicated the time of the last occupant that reaches to each door and the door usage (number of occupants that exit through that door) to all simulations.

Table A7-1: Compilation of Exit Door Flow Rate and Usage Results Simulations 1 to 3

	Simulation 1		Simulation 1A		Simulation 2		Simulation 3	
	t_last_door	Usage	t_last_door	Usage	t_last_door	Usage	t_last_door	Usage
Door	[s]	occ.	[s]	occ.	[s]	occ.	[s]	occ.
MainDoor	397,6	511	320,4	504	133,3	160	117,2	151
ED1	385,0	346	322,9	354	112,1	104	101,4	102
ED2	670,7	674	568,6	646	124,5	133	127,3	136
ED3	733,1	622	565,9	628	163,4	135	148,1	127
ED4	235,4	190	201,8	225	190,1	174	173,7	157
ED5	224,8	141	199,1	124	164,0	175	165,0	183
ED6	-	-	-	-	115,7	125	123,0	141
ED7	-	-	-	-	181,0	187	184,2	184
ED8	-	-	-	-	191,2	193	184,0	193

ED9	-	-	-	-	126,1	117	111,1	119
ED10	-	-	-	-	133,6	106	121,1	98
ED11	-	-	-	-	116,8	94	130,2	77
ED12	-	-	-	-	182,6	137	183,3	123
ED13	-	-	-	-	187,5	148	182,9	161
EDstore3	-	-	-	-	173,3	168	163,2	161

Table A7-1: Compilation of Exit Door Flow Rate and Usage Results Simulations 4 to 7

	Simulation 4		Simulation 5		Simulation 6		Simulation 7	
	t_last_door	Usage	t_last_door	Usage	t_last_door	Usage	t_last_door	Usage
Door	[s]	occ.	[s]	occ.	[s]	occ.	[s]	occ.
MainDoor	110,8	147	110,8	147	125,4	180	127,6	174
ED1	107,0	108	107,0	108	117,4	120	129,2	125
ED2	127,3	136	119,1	128	126,1	135	116,3	131
ED3	198,9	127	141,4	121	140,4	126	134,8	123
ED4	173,7	157	163,2	146	154,8	140	164,6	155
ED5	165,0	183	150,5	173	131,8	171	125,3	153

ED6	113,1	99	113,1	99	112,2	126	112,7	127
ED7	198,1	141	196,4	149	138,7	134	137,5	132
ED8	197,7	199	201,5	185	211,2	180	252,0	194
ED9	127,4	139	127,4	172	126,4	148	122,1	145
ED10	132,6	110	132,6	110	124,9	116	138,8	119
ED11	118,4	85	118,4	85	0,00	0	0,00	0
ED12	197,6	157	192,5	146	140,7	112	137,9	112
ED13	191,9	163	189,8	179	199,3	203	165,5	166
EDstore3	174,0	161	173,6	162	226,1	203	251,1	223



## Annex 8- Views of Terminal A Simulation Geometries Generated (Navigation Meshes)

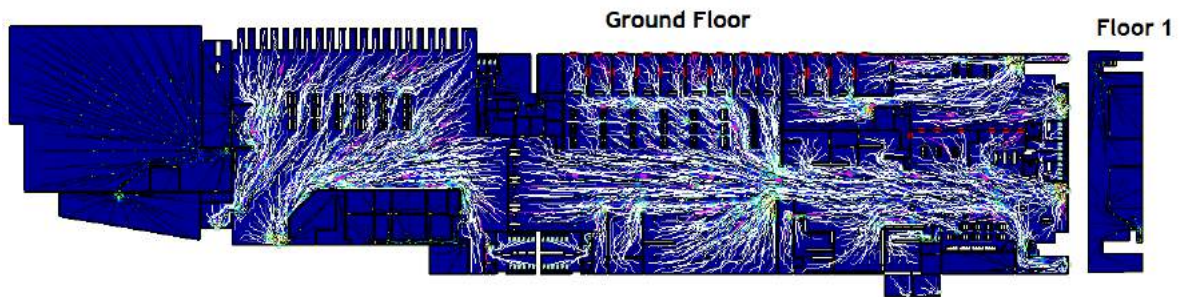


Figure A8-1: First Simulation (1) Occupants' Egress Routes

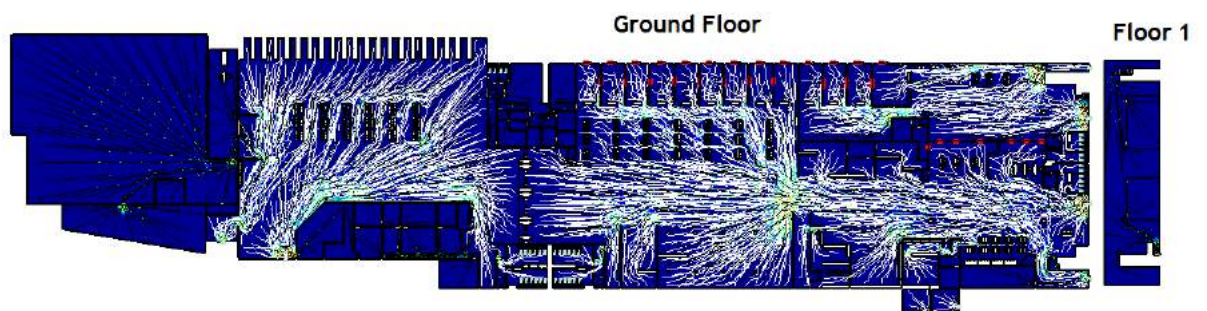


Figure A8-2: First Simulation (1A) Occupants' Egress Routes

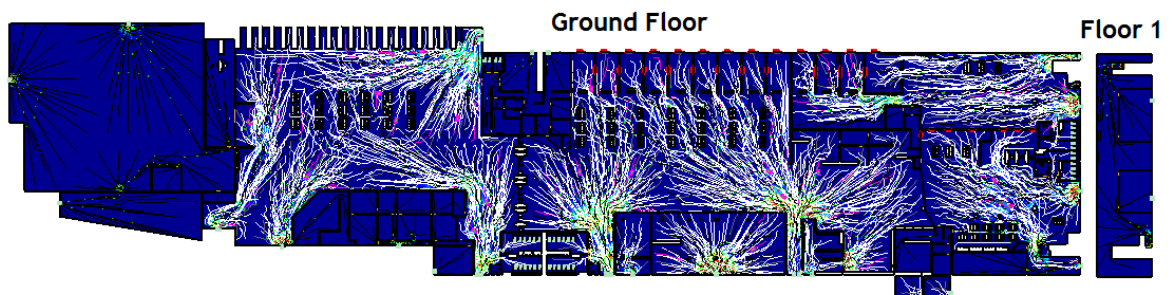


Figure A8-3: Second Simulation Occupants' Egress Routes

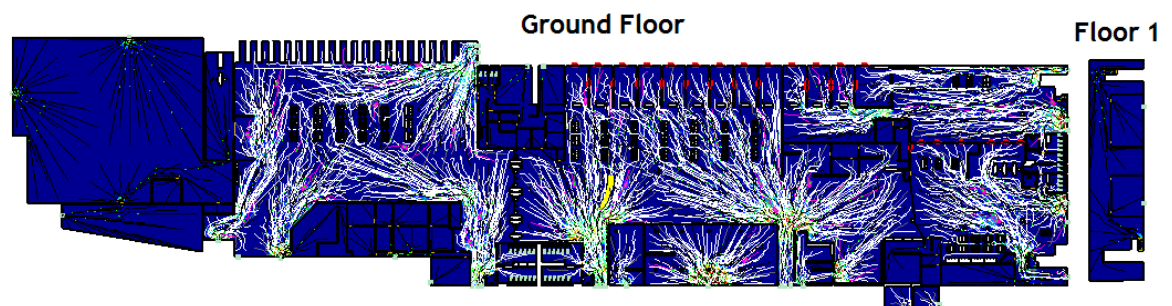


Figure A8-4: Third Simulation Occupants' Egress Routes

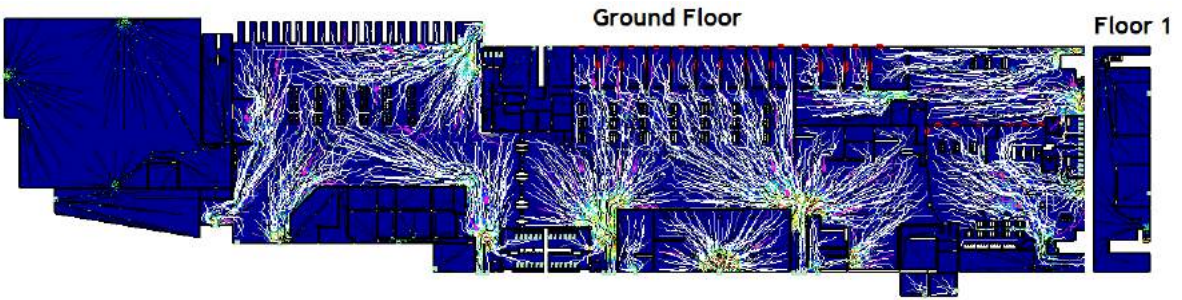


Figure A8-5: Fourth Simulation Occupants' Egress Routes

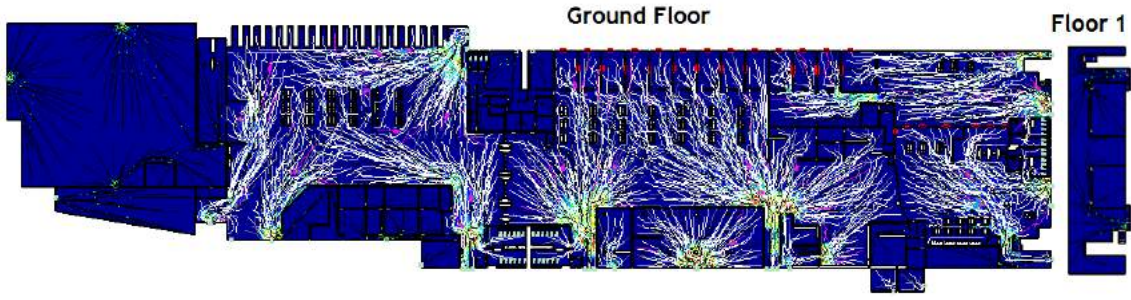


Figure A8-6: Fifth Simulation Occupants' Egress Routes

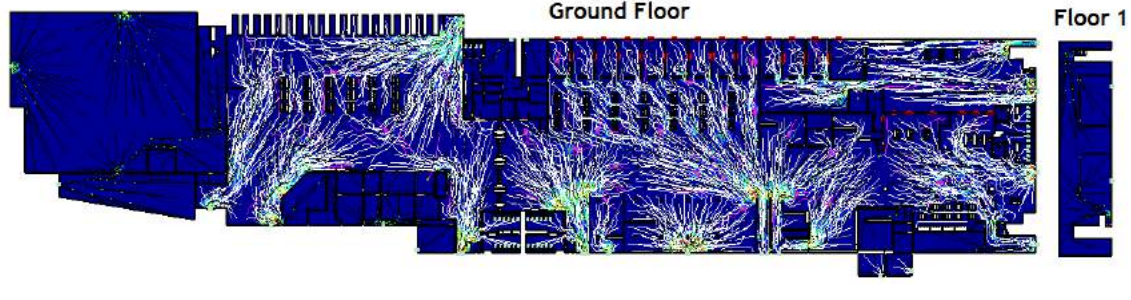


Figure A8-7: Sixth Simulation Occupants' Egress Routes

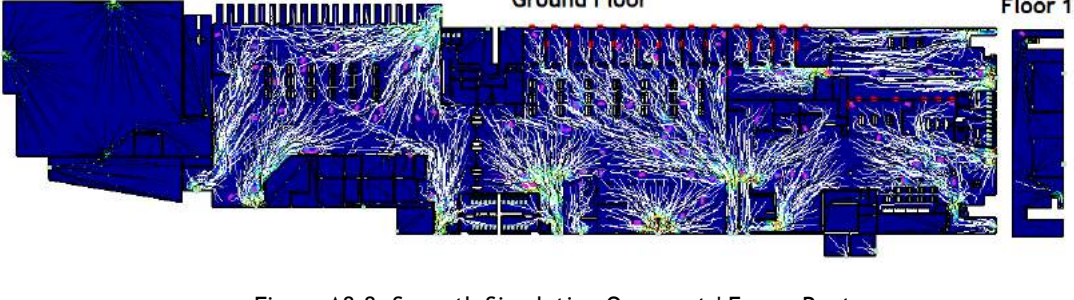


Figure A8-8: Seventh Simulation Occupants' Egress Routes

## **Annex 9- Scientific Communications/Articles Accepted for Presentation/Publication**



**1. Scientific Communication and Article Accepted for Presentation and Publication at the 14<sup>th</sup> International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED)**



# CONSTRAINTS IN THE AIRPORTS EMERGENCY PROTOCOLS FOR PASSENGERS WITH REDUCED MOBILITY

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## Abstract

Currently, airports emergency cases are becoming more common and, therefore, it becomes extremely important to have good emergency and evacuation protocols that are easily and quickly applied so that the number of the affected is minimized. The simulation of these emergencies is important to implement these evacuation plans and to have an evaluation of the plan. These evacuation and containment plans are often idealized to passengers that in case of emergency are self-sufficient, able to physically attend to themselves in their evacuation from the airport, not being optimized for passengers with reduced mobility that require assistance from others, and thus more time for evacuation. This study aims to understand and identify key issues with regard to how passengers with reduced mobility are considered in the current protocol plans and how in practice these are actually applied. For that, we performed an analysis related to the airport emergency protocols that are currently applied at European level, where we found that in fact there are large gaps in relation to what is defined in international law is that which is applied in practice. One of the major flaws in the implementation of these protocols are the set times for evacuations that do not contemplate at all situations of reduced mobility that are dependent on outside help. Their own infrastructure also present some obstacles in emergency situations, particularly in the case of energy cut where there is no alternative transport for people in wheelchairs, because most emergency access only present stairs as an alternative to elevators or the escalators.

*Keywords: emergency protocols, emergency accesses, reduced mobility*



**2. Scientific Communication and Article Accepted for Presentation and Publication at the International Conference on Engineering ICEUBI 2015**



# Airport Emergency Protocols for Passengers with Reduced Mobility: Constraints and Possible Solutions

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## Abstract

Airport emergency cases are becoming more common; therefore, it becomes extremely important to have good emergency and evacuation protocols that are easily and quickly applied so the number of the affected is minimized. The simulation of these emergencies is important to implement evacuation plans and evaluate them. Evacuation and containment plans are often idealized to passengers that in case of emergency are self-sufficient, able to physically attend themselves in their evacuation from the airport, not being optimized for passengers with reduced mobility that require assistance from others, and thus more time for evacuation. This study aims to understand and identify key issues with regard to how passengers with reduced mobility are considered in current evacuation plans and how in practice these are actually applied and also understand which possible solutions exist to solve the major flaws of these protocols. For that, we performed an analysis related to the airport emergency protocols and regulations that are currently applied at European level, where we found that in fact there are large gaps in relation to what is defined in international law is that which is applied in practice. One of the major flaws in the implementation of these protocols are the set times for evacuations that do not contemplate at all situations of reduced mobility that are dependent on outside help. Airports infrastructure also present some obstacles in emergency situations, particularly in the case of energy failure where there is no alternative transport for people in wheelchairs, because most emergency accesses only present stairs as an alternative to elevators or the escalators.

Keywords: emergency evacuation protocols, emergency accesses, reduced mobility.