The Impact of Demographic Characteristics on the Egress Time

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Abstract

Emergency evacuation in case of an emergency is a crucial problem in all kinds of buildings, as many occupants are in a limited amount of space. It is crucial to comprehend how demographic factors affect the amount of Required Safe Egress Time (RSET) to improve building safety design and evacuation procedures. To explore the effects of demographic factors, such as age, gender, cultural differences, and fitness level, on the RSET time, simulations based on Pathfinder are carried out. To ensure the validity of this study, the movement speed was determined through a review of the literature. Relationships between the demographic characteristics and RSET will be presented, and a comparison between hand calculation and numerical simulation will be made. Hopefully, this paper can provide insight into the models and data selection on egress simulation.

Keywords: Egress Simulation, Models Selection, Apartment Evacuation

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Introduction

Building evacuations can be required in the event of a fire, severe weather, or other emergencies. As emergency egress is required, the egress system needs to enable the people to reach a relatively safe point. However, being said that the building design is of great significance, the occupants of the building will also impact the overall egress time. There is a great number of papers focusing on the effects of human characteristics and human behaviors on the egress time Spearpoint and MacLennan (2012) Siddall, Stevenson, Turner, and Bilzon (2018) . This paper will investigate the effects of some demographic characteristics, like age, gender, fitness level, and cultural difference on the RSET time.

Numerical analysis, namely simulation, has been widely applied in the research on human evacuation for its convenience in setting the parameters and its low cost Wu and Mizuno (2019). However, the essential problem that all simulations have to face is the choice of models and parameters. Hoskins pointed out that even though there are currently dozens of simulation models available for the designer to choose from, the models are not well-validated Hoskins (2011). However, the shortcomings of the software's default parameters have been examined Gwynne (2010), particularly about the occupant reaction, also known as movement and behavior, which enables the simulation tool to function and produce results. The users must comprehend the effects of using and applying this data.

Pathfinder is an advanced movement simulation combined with high-quality 3-D animated results, and it can provide reliable solutions to evacuation at a quick speed, developed by Thunder Engineering. Pathfinder has lots of features, making it the first choice of researchers and engineers on egress simulation, like the wide range of importing formats, the continuous movement mesh, the steering mode, and SFPE mode, the movement groups, customizable populations, and the detailed data output. No wonder that the Pathfinder is one of the fundamental tools of several papers in prestigious journals.

In the present paper, the effects of people's characteristics will be investigated based on the simulation through the pathfinder of a three-story apartment. The movement speed used in the simulation will be selected from peer-reviewed articles. Parameters like age, gender, fitness levels, and cultural differences in pre-action will be examined. This paper will provide a comparison between the hand calculation of RSET with the numerical results. At last, a discussion will be made to excavate the underlying mechanism between the demographic characteristics and egress time and indicate the difference between model prediction and simulation projection.

Literature Review

For years, the research on building evacuation on simulation is a hot topic, and data on the movement speed and pre-evacuation time due to culture have been published. This section will present the results of the literature review and how the required information for egress simulation is selected from the numerous research and integrated into the Pathfinder. First, a list of peer-reviewed papers and some engineering handbooks published in prestigious journals and reliable publishers will be reviewed to find some useful information and some supportive data.

The general structure of this section will be a subsection summarizing the data derived from the handbooks, and a subsection discussing the data from the peer-reviewed articles. At the end of each section, brief conclusion will be made on the selected data of movement speed and pre-evacuation time.

Movement Speed

The term "Movement Speed" used in the present paper is the unimpeded movement speed of the individual occupant in the simulated building. In the research on the egress movement speed, there are two kinds of perspectives, namely macroscopic models and microscopic models. Due to the lack of literature, the review section will talk about the characteristics of groups within the simulations, however, for the implementations, only the macro characteristics like the mean speed and the standard deviation will be provided. The speed on stairs will not be taken into consideration in this paper, as it will be automatically calculated by the Pathfinder.

In terms of the factors influencing the movement speeds, most researchers are interested in the distribution of men/women within the structure, the age of the occupants simulated, the body size of the occupants simulated, and the presence of occupants with disabilities. Notice that here the body size of the occupants involved in the simulation might have two aspects of effects, namely the width of the shoulders and the impact of fitness level on the movement speed Hurley et al. (2016).

The SFPE Handbook of Fire Protection Engineering is a powerful tool for fire safety engineering and also a solid reference for the model and data selection of egress simulation. A basic review of the movement speed can be referred to the Chapter 64 of this handbook. And a basic movement speed regarding gender and age can be figured out. A short summary on the data derived from the handbook can be referred to as Table 1

It can be observed that within the scope of the literature review on the handbook, most of the information and engineering data focus the influence of gender and age on the movement speed. There are also lots of other researchers who used the movement speed of different population characteristics in their research environment. Severl other publications on this field have beed reached out. The effect of an aging and less fit population on the ability of people to egress buildings is investigatedSpearpoint and MacLennan (2012). Here I have grab some of their figures to represent the quantative relationships between the age, fitness level, which is represented by the BMI and body weight in this paper, with the movement speed. Figure 1 illustrates the relationships between the age, gender and walking speed. Notice that here as the author did not give the exact value of the walking speed, what I can to is to extract the value from the graphic. Figure 2 depicted the walking speed as a function of BMI values. Still, since the original data is not available to me, I have to find the approximated value of the walking speed. Similarly, Figure 3 is the relationships between the normalized walking sped data and the reduction factor equation, which is adopted to relate the changes in walking speed with BMI.

To sum up, in this section, movement from handbooks and peer-reviewed articles are selected and data are extracted. The mean value of the movement speed is 3.42 ft/s, the minimum value is 1.378 ft/s, the maximum movement speed is 5.48 ft, and the standard deviation is 2.7 ft/s.

Pre-Evacuation Time

The Pre-evacuation time is defined as the interval between the time at which a general alarm signal or warning is given and the time at which the first deliberate evacuation movement is made, consisting of two components, recognition time and response time. The recognition time is the interval between the time when the signal is perceived and the time when the occupant interprets this signal, and the response time is the interval between the recognition time and the time at which the first movement is made. In this paper, no detailed identification will be made between the two times as it is handled in most literature and engineering practice. The literature involved in this section provides some guidance on data that could be used to represent the effect of cultural differences on the pre-evacuation time, by collecting the data from different countries Hurley et al. (2016). A short summary on the data derived from the handbook can be referred to as Table 2

Like what is mentioned in the last section, a basic review of the pre-evacuation can be referred to in Chapter 64 of the SFPE handbook. For the occupant type involved in this paper, namely the apartment, the handbook provides four papers on different countries. From this it can be seen that the UK has the average lowest pre-evacuation time, then the US, which is slightly higher than the UK. However, Canada has the longest evacuation time which is 3 to 8 minutes.

Though the Pathfinder all the users to assign the pre-evacuation time individually, such operation implicitly simulates the different responses that may be expected given the role and activity of those involved. And the effects of such an operation, which is examined by me by interests, turn out not to have no significant change to the simulated egress time. To view the cultural difference on a holistic level, an average is assigned to the entire population, being less sensitive to the differences of the individuals.

Soltanzadeh et al evaluated the effect of refuge floors in combination with egress components in high-rise buildings based on simulation Soltanzadeh, Alaghmandan, and Soltanzadeh (2018) . Their work provides us with a way how to integrate all the movement speeds, and perhaps other human characteristics like pre-evacuation time to several usable parameters to be used in Pathfinder. They put up with a method with the mean value from all selected values, and personally assign multipliers to the standard deviation. That being said, in their work, their movement for people with disabilities is 0.8.

So, in the present paper, I will comprehensively integrate all the information from the listed papers. For both the movement speed and the pre-evacuation time, I will record the minimum, the maximum, the mean, and the standard deviation. That is to say, the mean value of the movement speed is 3.42 ft/s, the minimum value is 1.378 ft/s, the maximum movement speed is 5.48 ft, and the standard deviation is 2.7 ft/s. As for the pre-evacuation time, as the apartment is assumed to be built in the U.S., the mean value is 52.7s, and the lowest and highest value is 9s and 104s individually. The cultural differences of the individual will be assigned to specific occupants to indicate their effect on the overall egress time.

Numerical Setup

Then, the numerical simulation based on the Pathfinder will be conducted on a three-theory apartment. Pathfinder is a powerful research tool on egress simulation developed by Tunderheading Engineering Software, and numerous papers have been published based on it Mu, Song, Qi, Lu, and Cao (2014)Ronchi, Uriz, Criel, and Reilly

(2016).

In the present paper, the egress simulation based on a three-story, accessible apartment that is 100 ft by 200 ft will be conducted. An obstruction such as rooms, shelves, and other things like fire equipment boxes will be taken into consideration. On the ground floor, there will be the main entrance and a secondary entrance in the middle of the 100 ft long wall. On the upper floors, there are stairs at corners at opposite corners, and the one near the main entrance does not have a door into it from the ground floor.

Apart from these basic requirements, there is also some additional design for the apartment near the university. Figure depict the general scenario of the building. First of all, in the middle of the 200 ft wall, there will be mechanical rooms and riser rooms on one side where no occupants will normally be present there. On the opposite is the relaxed area of the building. The first floor is the gym, the second floor is a dance room, and the third floor is the computer room, where more occupants will be present. It is also worth noting that in the middle of the building, there is also an inside stair for the occupants to freely move from floor to floor. A simple illustration of the evacuation scenarios can be seen in Figure 4

To make the egress simulation more reproducible, here the width of the means of egress and the dimension of other components will be given.

The occupant's type of apartment in the NPFA 101 and IBC 2018 claimed that the occupant load factor is 200ft2/person. As the area of each floor is 20000ft2, there should be no more than 100 people on each floor. In the present model, both the requirements for each floor and the holistic building are required. What's more, code requirements on egress components are also carefully reviewed.

Based on the aforementioned literature, the mean movement speed in this paper will be 3.42ft/s, and the standard deviation will be 2.7ft/s. For most people, the mean pre-evacuation time will be 52.7s, and some selected ones will have different movement speeds and pre-evacuation to represent the effects of the demographic characteristics. It is worth noting that to make the simulation more realistic, the height and shoulder width of the occupant has been modified. And some occupants are assigned some specific movement speed and pre-evacuation time to represent the effects of geographic characteristics.

From the simulation results, it can be found that it takes 175.3s for a total of 205 occupants to evacuate from the apartment. So, the RSET from the numerical simulation is 173.5s.

On the results file of the Pathfinder, it can also be found that the minimum time of the evacuation, namely how long the first people escape, is 10 seconds. And it takes 70.1s on average for the people to egress. The travel distance, by the way, is 170.2ft on average, and 272ft on maximum. There is still much more information in the results file, and for further research, it might be interesting to compare other calculation methods from the SFPE or FPST handbook, like higher-order approximation. It might not only be beneficial to the code revision but also to the design of the egress simulation results.

Hand Calculation

The hand Calculation of the RSET can be referred to for detailed information in Fire Protection Handbook Cote (2016). In the present paper, only the first-order approximation will be used for the convenience of calculation.

There is a total of five steps in the hand calculation of the RSET time. First, several assumption should be made. Then, the flow capability of a stairway should also be estimated based on the assumptions before. Thirdly, the flow through a door should be estimated. Next, based on the calculated stairway flow, the speed of movement will be estimated. Finally, add up all the time, we will have the building evacuation time.

The next part of this paper is to actually calculate the RSET based on the models used in the Pathfinder. Regarding to the example of the Fire Protection Handbook and its first order approximation, the numbers required in this calculation will firstly be listed.

1. There are three floors, 200ft x 100ft

2. Floor to floor height is 10ft, however, the height of the ceiling is not taking into consideration
3. There are three stairways, located at two opposite corner of the apartment and in the middle of the apartment.
4. Each stair is 44 in
5. Stair riser are 7 in wide, treads are 11 in high
6. There are two 5ft x 10ft landings per floor of stairway travel
7. The first floor does not exit through stairways

So, now the calculation can be started

1. First of all, the priming controlling factor will be either the stairways or the door discharging from them. Therefore, the specific flow, F_s , will be the maximum specific flow, F_{sm} . All occupants start egress at the same time, the population will use all facilities in the optimum balance.
2. Based on Table 4.2.4 of the Fire Protection Handbook, the effective width W_e is 32in, and that for the door is 24 in. So the maximum specific flow is 18.5 person/min/ft. So the flow from each stairway is limited to 55.5 persons/min.
3. The maximum specific flow through any 36 in door is 24 personns/min/ft. Therefore, the flow is controlled by the stairway exit doors.
4. Then, the speed of movement can be calculated from the equation $S = k - akD$, which is 105 ft/min. Then, the travel distance on the stairways is 38.5ft . So the travel time for a person moving with the flow is 0.37 min.
5. Finally, the building evacuation time can be calculated. In this case, it should be 4.79min , or 288 in seconds.

Results and Discussion

This section will briefly conclude what can be derived from the present paper, namely from the data review, the results of numerical simulation and the hand calculation. Then, comparison and discussion will be made between these two results to indicate the effects of human characteristics on the egress time.

From literature review, it can be concluded that generally speaking, man have a higher movement speed than that of women, and the unimpeded movement speed reach it peak at around 20, and decrease since then. By common sense, the higher the movement speed is, the shorter will the egress time be. As for the cultural difference, people from Canada illustrate a significant higher pre-evacuation time than the U.S. and the U.K. Then I will compare the egress time from hand calculation and the egress simulation. It turns out that the hand calculation have a significant higher egress time than that of the simulation. It might be easily explain by the fact that the model I choose in the Pathfinder is actually not fit the assumption of the first order approximation of the hand calculation of RSET. Actually, in the case of this paper, the egress time is not priming limited by the two stairs at the corner, as I have add a stair in the middle, which reduce the egress time by over 50%.

To sum up, this essay compares the effects on the demographic characteristics on the hand-calculated egress time and that from the numerical simulation through Pathfinder on a three-story apartment. It also examined the importance of the models selection and parameter selection on the egress time. It found that adding a stair on proper space can significantly reduce the egress time.

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Table 1

Movement Speed Summaried from Handbook Cote (2016)

Source	Country	Mean(s)	Lowest Time(s)	Highest Time(s)
Gwynne	USA	51.7	28	104
Shields et al	UK	43.8	6	157
Brennan	Australia		60	1200
Proulx; Proulx and Fahy	Canada	542		

Table 2

Pre-Evacuation Time Summaried from Handbook Cote (2016)

Source	Country	Collection Method	Mean(ft/s)	Max Speed(m/s)	Min Speed(ft/s)	Notes
Zanlungo et al	Japan			3.772	4.264	
Tanaboriboon	Thailand	Video	4.0016	3.5752	4.428	adults
Tanaboriboon	Thailand	Video	4.0344	3.6736	4.3952	young
Tanaboriboon	Thailand	Video	2.6896	2.2632	3.116	elderly
Berrou et al	HK	Video	4.57	5.26	3.88	

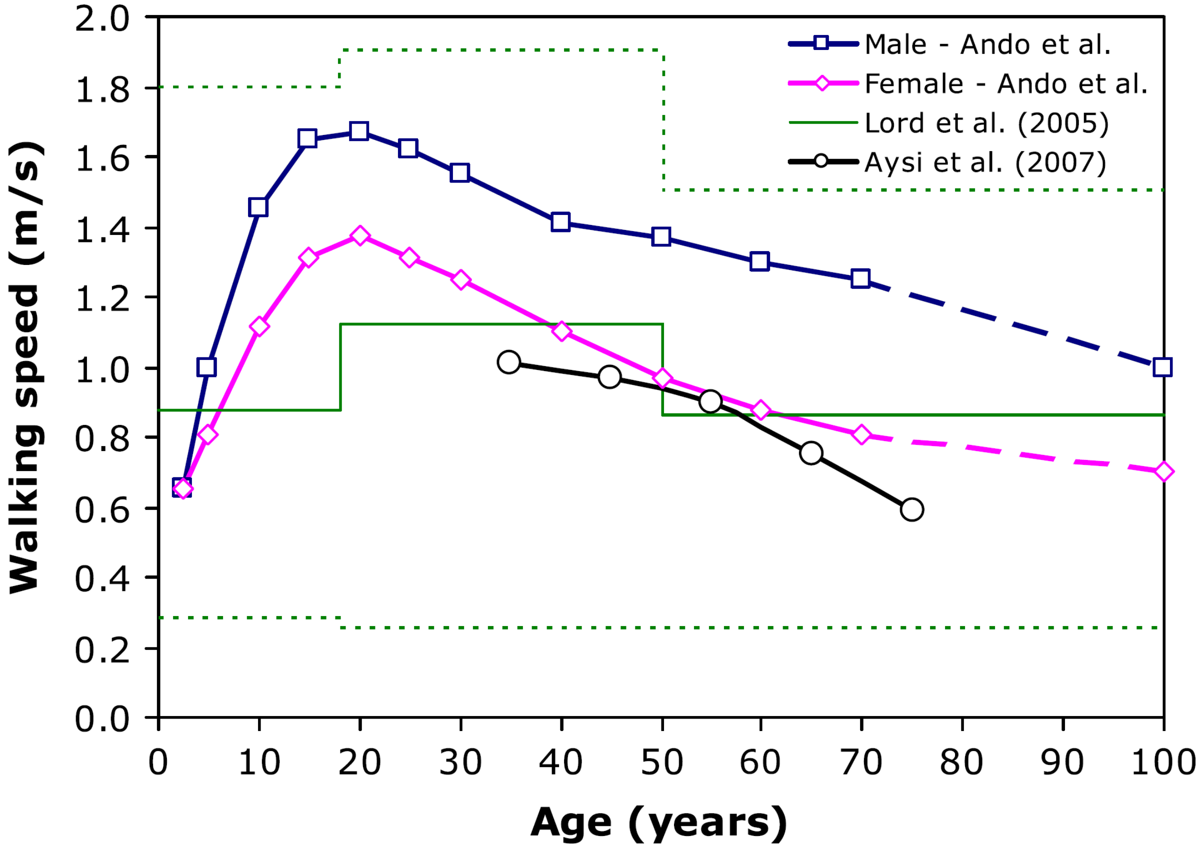

Figure 1. Comparison of walking speed as a function of gender and age

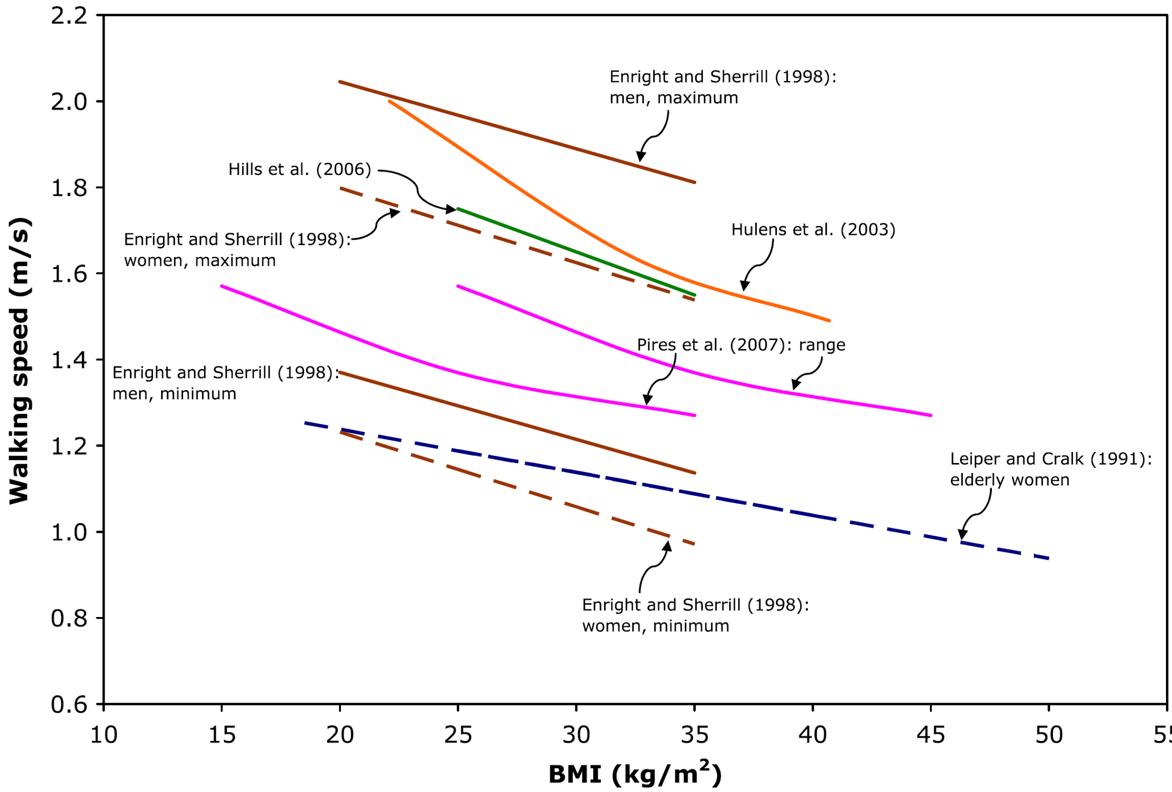

Figure 2. Walking speed as a function of BMI values given by various researchers.

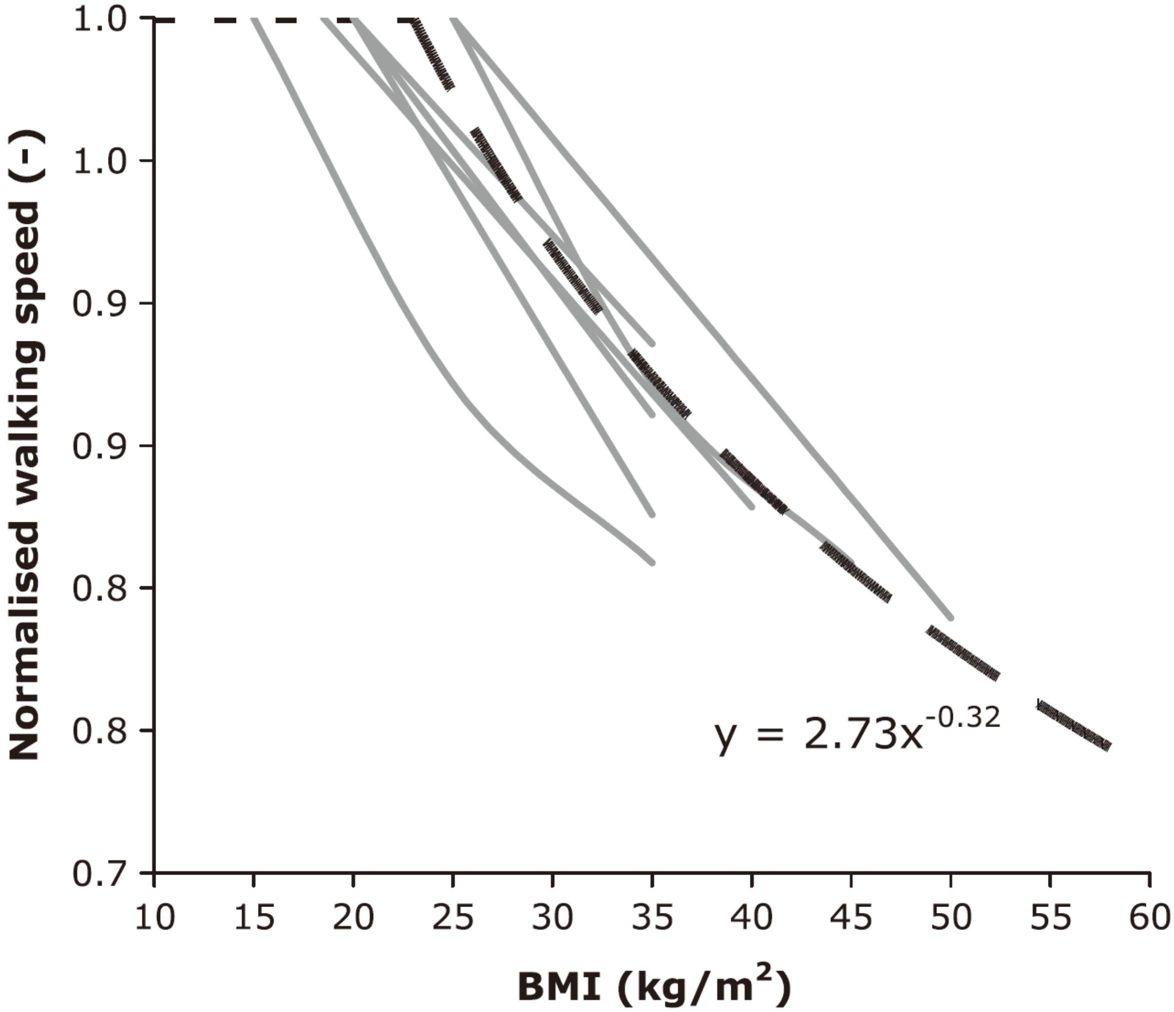

Figure 3. Normalised walking speed data and the 'reduction factor' equation (shown as the dashed line) used to relate change in walking speed with BMI

Figure 4. A Simply Illustration on Each Floor of the Model used in Pathfinder