APPENDIX A2: PROPOSED EXEMPLAR BUILDING AND MODEL PARAMETER SELECTION

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A2-1 Introduction

The principal aim of **Objective A2** is to quantify the evacuation performance in response to a representative set of scenarios. The scenario development can be broken down into two explicit aspects: the building design and occupant numbers, and the occupant characteristics / behaviour. The building design aspects are related to the work in **Objective A1** (Appendix A1) and much of the latter comes from the work of **Objective B1** (see Appendix B1) and **Objective B2** (see Appendix B2). It is not the aim of this work to explicitly address details with regard to fire development, toxic gas concentrations etc., as these are highly complex phenomena. Instead, the fire will be represented in a simplified form in terms of its impact on escape. How this is to be done is explained later in this document.

Figure A2-1 shows the integration between the various objectives and how these objectives combine within the project. The stage of the process corresponding to this note is shown in grey as 'Building and scenario development'.

Combined with establishing a possible range of credible fire scenarios considering the initial occupant distribution, evacuation procedure, delays, etc., it is necessary to develop a 'common' high-rise residential building (i.e., the exemplar building).

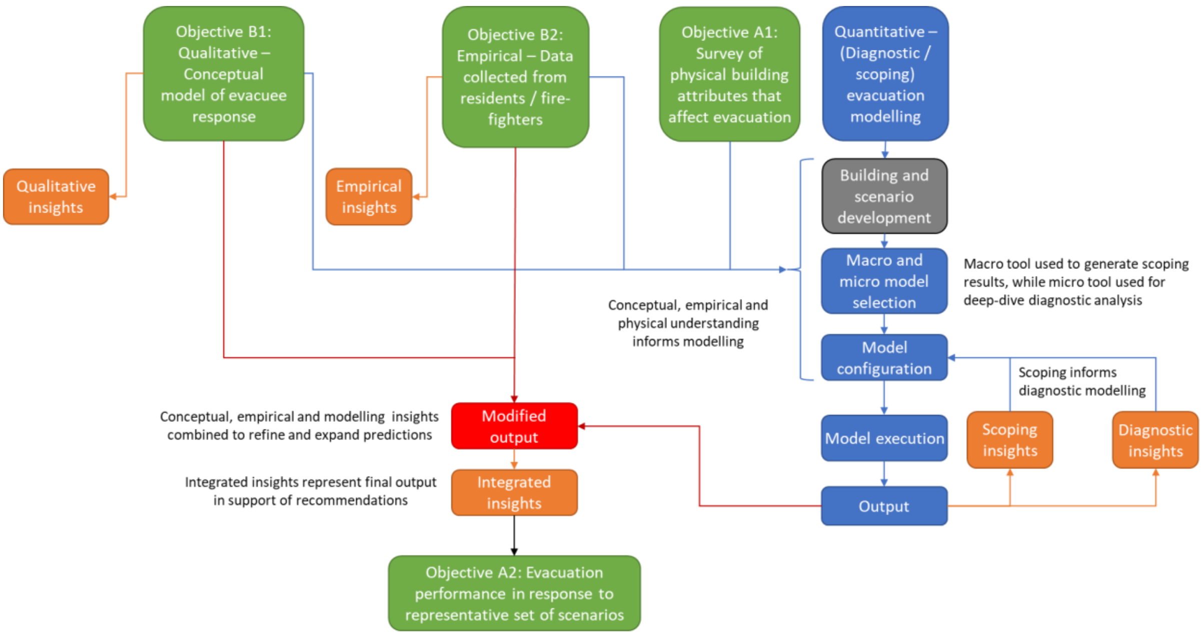

Figure A2-1 Flow chart showing the integration of the objectives, current stage shown in grey

In the next section the core aspects of the evacuation scenario are described – the building designs and the occupant population. This understanding will allow appropriate models to be selected and then a set of scenarios to be established.

A2-2 Exemplar high-rise residential building

A2-2.1 Floorplate of a 'common' building

Considering the nature of the built environment and a general desire to design individual buildings, it is difficult to define what constitutes a 'common' high-rise residential building. However, previous work by Hopkin [1] sought to define a 'common' single stair high-rise residential building premised upon maximising the number of flats per floor in a 'code-compliant' building. Approved Document B: Volume 1 (ADB) [2] was utilised, as one of the primary fire safety guidance documents in use in England. In ADB, diagram 3.7a allows for the most efficient use of a single stair building in terms of number of flats per floor (and thus maximising the resident population). Through a probabilistic assessment of the relevant data, Hopkin determined the average number of flats per floor to be seven. Figure A2-2 shows the resulting floorplate of the single stair residential building comprising a mix of 1-, 2- and 3-bedroom flats.

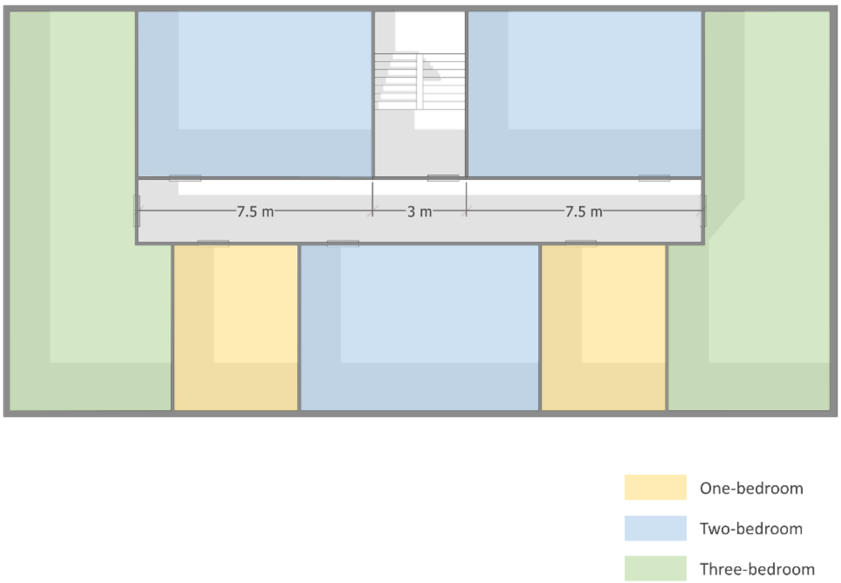

Figure A2-2 Exemplar building with single stair

Given that single stair high-rise residential buildings can be considered to pose a higher risk to occupants (when compared to buildings with multiple stairs), for completeness, this project will also consider a building with two stairs (note, this is the minimum expectation for high-rise residential buildings over 18 m in Scotland [3] and may also form part of the guidance in an upcoming revision to BS 9991 'Fire safety in the design, management and use of residential buildings – Code of practice'). To minimise the number of variables, and in the interest of comparing like-for-like, a similar building footprint will be used, with each floor having seven flats and a stair at either end of the common corridor, as shown in Figure A2-3.

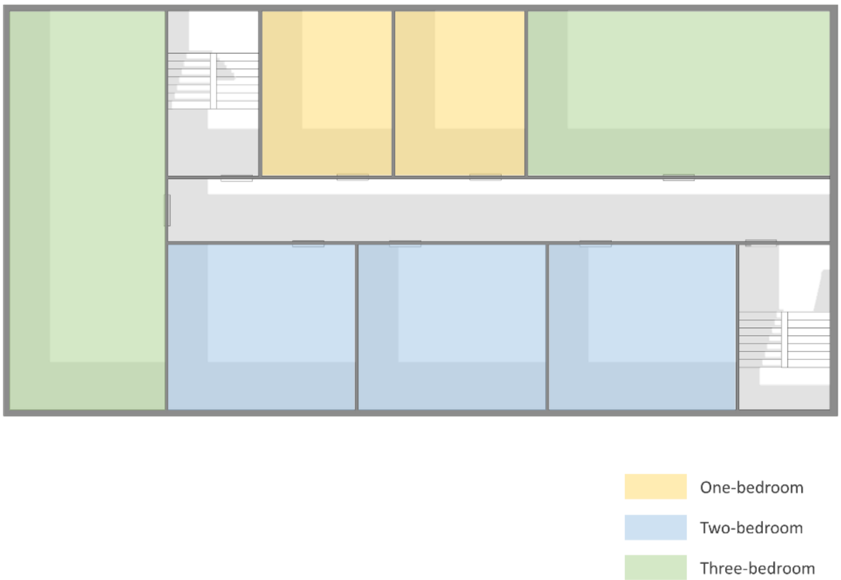

Figure A2-3 Exemplar building with two stairs

One aspect of the modelling will be varying the dimensions of key aspects of the design, such as the widths of stairs and exits, to evaluate their impact on the evacuation performance. To keep the number of scenarios to a manageable level, widths will be investigated in terms of 'single' and 'double' widths rather than through smaller graduated steps. Similarly, corridor lengths will be increased by using multiples of the seven-flat footprints at both ends of the exemplar building (with the additional associated stairs omitted) appended to the original ADB-compliant design(s).

The buildings will also need to have appropriately located lobbies and cross corridor door configurations where relevant to a given scenario. In addition, although not shown on the footprints in Figure A2-2 etc., where appropriate to a scenario the stair core/s can include a lift shaft. The topic of lifts is discussed further in Section A2-3.3.

A2-2.2 Building height of top storey

The single and two stair building floorplates described in Section A2-2.1 have been considered for four building heights of 11 m, 18 m and 30 m, and greater than 50 m. Three of the four top storey heights have been selected for relevant ADB guidance implications (or trigger heights), given in Table A2-1, with the latter selected to capture taller buildings. For this assessment, the building height specifically refers to the distance from ground floor, assumed to be the fire and rescue service access level, to the floor level of the upper most qualifying storey, consistent with the definition given in ADB for the height of the top storey in a building. It is proposed that the exemplar buildings will be configured to the maximum height within the first three trigger height classifications (i.e., marginally under the trigger height) to maximise the occupant load. The exemplar tall building over 50 m will be of the order of 170 m as this is similar in height to the tallest proposed, single stair residential building that could be identified at the time of writing (Cuba Street, London [4]).

Table A2-1 Trigger height and their corresponding design implications

Building height	Relevant ADB design implications
11 m	The height at which a sprinkler system should be provided in new building construction; and The minimum period of fire resistance is increased to 60 min from 30 min.
18 m	The height at which it is recommended to include a firefighting shaft; and The minimum period of fire resistance is increased to 90 min.
30 m	The minimum period of fire resistance is increased to 120 min.
170 m	The tallest proposed, single stair residential building that could be identified at the time of writing [4].

A2-2.3 Additional building considerations

A2-2.3.1 Amenity spaces

From the outcomes of **Objective A1** (specifically **Task A1_3**), participants in the interviews conducted at that stage highlighted a clear trend in the use of shared amenity spaces. Therefore, the inclusion of amenity spaces will be considered in the modelling to capture the increasingly common provision of such spaces in high-rise residential buildings. For the purpose of **Objective A2**, the specific use of the amenity space is not critical; however, such spaces may include gyms, cafés, cinemas and roof terraces, for example. Typically, as part of the fire strategy, these spaces will operate a simultaneous evacuation strategy for relevant fire scenarios, as defined by the designer.

In reality, the location of amenity spaces within the building varies. These can be located mostly at low levels, perhaps with their own dedicated means of escape, or can be located further up the building, utilising the stair(s) that serve the residential portion of the building. For roof terraces, for example, the latter is almost always the case. The modelling will not address those spaces at lower levels that have a dedicated means of escape as this will not impact the evacuation strategy for the remainder of the building. Rather, the focus will be on amenity spaces that share a means of escape with the residential portion of the building, to capture the effect on these spaces that may have on the overall evacuation strategy. Different amenity locations will be considered within the modelling including part way up the building and at roof level.

A2-2.3.2 Means of warning

The means by which occupants are made aware of a fire event is integral to the development of the scenarios. The means employed will have a profound effect on the response of the occupant population – especially the initial delays incurred prior to evacuating. For this project, three means of warning will be considered in the modelling to assess the effect, if any, these have on the building evacuation:

- Local sounder alarm (the current minimum expectation in ADB) – an audible alarm only in the flat / floor of fire origin;
- Global sounder alarm – an audible alarm throughout the building; or
- Global voice alarm – an audible alarm throughout the building providing instruction / information to escaping occupants.

Note, both global warning systems exceed the recommendations of ADB. Consideration will need to be made on whether the global alarms are assumed to activate immediately on fire detection or could be delayed until some other stage. These scenarios will include representing the potential performance of evacuation alert systems (EAS) as defined by BS 8629 [5] in which the fire and rescue services may wish to initiate the evacuation of individual floors, or the entire building.

A2-3 Defining the building occupancy

A2-3.1 Number of occupants

A2-3.1.1 Residents

Extensive work has been undertaken by Hopkin et al. [6] to determine the occupant density of dwellings, looking at both houses and flats (apartments). Considering the latter in isolation, and specifically with respect to high-rise residential buildings, two methods of determining the building occupancy were proposed by Hopkin et al.:

- Method 1: Utilise occupant density distributions and the floor area,
- Method 2: Utilise the number of occupants per bedroom and the number of bedrooms per dwelling.

The resulting distribution of each method was found to be lognormal, with a corresponding derived mean value and standard deviation for high-rise residential buildings of 37.8 m^2/person and 20.9 m^2/person, respectively, for Method 1, and a mean value of occupants per bedroom of 1.19 and standard deviation of 0.67 occupants per bedroom for Method 2.

Based on the assessment, it is postulated by Hopkin et al. that Method 2 (number of occupants per bedroom) provides a more reasonable indication of the number of occupants who may be sleeping in the accommodation. However, it is noted that Method 1 is generally more conservative and may be representative of the potential for additional occupants over those solely registered to the property.

At this stage of Objective A2, neither method is definitively selected. Rather, the more conservative of the two methods with respect to the exemplar building will be adopted. In the modelling, for either method, it is proposed to utilise the lognormal distribution of values to best capture the probabilistic nature of the occupant loading.

A2-3.1.2 Visitors

On top of building residents, it may be possible for the amenity spaces discussed in Section A2-2.3 to be occupied by visitors that would not be necessarily accounted for by the methods described in Section A2-3.1.1.

OFR can interrogate its collection of past and ongoing projects to establish credible amenity occupancy loading scenarios that may see an increased demand on the means of escape provisions in place in the model building. For the single stair building, a maximum per floor occupancy of 60 persons may be considered appropriate due to the single means of escape; however, it may be possible to provide two separated storey exits into the single stair, allowing for an increased occupancy. Therefore, the modelling of the single stair will consider a maximum, per floor occupancy of 110 persons, as per ADB. The same maximum per floor occupancy of 110 persons is proposed for the arrangement with two stairs due to the multiple choice of storey exits.

A2-3.2 Occupant demographic

The demographic of building occupants will be established through census data that is collected every 10 years.[1] This will provide information on the occupants including age, sex, etc. While many factors may not have bearing on the modelling, some, for example, native English-speaking ability, can influence a person's ability to respond to signals / instructions from the fire and rescue service or neighbours, given issues with comprehension.

Further, there is a clear demographic trend in the UK towards an aging population [7], along with elderly people being cared for in their own homes where possible rather than being moved to sheltered accommodation or care provision. **Objective A1-3** discusses this trend in greater detail, noting that it is increasingly likely that high-rise buildings will house older residents, including those with impaired mobility and/or cognition.

These variables will be difficult to capture in the modelling; however, should be considered, where possible.

A2-3.3 Mobility impaired persons (MIPs)

Subject to the nature of their disability and the features in place to support their evacuation, MIPs can take longer to evacuate than able bodied persons, for example see Kuligowski et al. [8]. Therefore, consideration of MIPs in the evacuation scenarios is a critical item as this can drive the overall evacuation time.

Traditionally, evacuation of MIPs has been through the provision of refuges located within protected areas of relative safety. With this strategy, it is expected that those who cannot readily self-evacuate can remain in the refuge for a period of time and await assistance with the next part of their movement to a place of ultimate safety. However, the London Plan [9], a new piece of guidance for developments in London, now recommends that each building core (for relevant buildings in London) should be provided with an evacuation lift for the evacuation of MIPs. This trend in the evacuation strategy for MIPs will be captured in the modelling, whereby occupants

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[1] https://www.ons.gov.uk/census/2011census

may be waiting to make their evacuation via a lift. The modelling, coupled with other analysis, will assist in assessing the benefit of using lifts for building evacuation.

Regarding the number of MIPs to consider within a building, both BS EN 81-76 (the design guidance for evacuation of persons with disabilities using lifts) [10] and the London Plan recommend that, in the absence of more detailed information, it should be assumed that 10% of the population of the building have some form of disability and may be unable to use stairs to evacuate. This value will be adopted in the modelling to account for the number of MIPs.

A2-4 Model selection

A2-4.1 Assessment criteria

The evacuation simulation work requires a two-stage process to examine the scenarios of interest. This is necessary given the array of scenarios to be examined. The two stages will involve:

- Stage 1: High-level examination of all scenarios. This is to capture the key dynamics, rank outcomes and prioritise scenarios for more refined analysis. These scenarios will be examined by using **Model A**.
- Stage 2: Refined examination of sub-set scenarios. A sub-set of the scenarios will have been identified as requiring further analysis in Stage 1. These will be examined by using **Model B**.

Stage 1 will provide a scoping study of key dynamics, while Stage 2 is a diagnostic investigation that will explore a wider array of underlying factors, interactions and examine a larger and more fundamental set of indicators of the simulated conditions. As such Model B needs to be more refined (representing evacuation dynamics at a more granular elements) and have a wider scope (capturing a more comprehensive set of evacuee actions) when compared to Model A. Model B is intended to represent individual evacuee performance and generate emergent conditions from this performance and evacuee interactions; Model B is intended to simulate the conditions produced by these interactions across a larger set of scenarios. This approach enables the analysis to focus on key designs of influence or interest. It also requires different modelling approaches allowing increased confidence in the results produced by model results – effectively benchmarking any insights made.

This requires careful selection of Model A and Model B to ensure that they can generate actionable results for use in the rest of the project tasks. There has been a significant amount of work categorising evacuation models. Given the relatively immature nature of this engineering field, the first comprehensive model reviews occurred in the last 25 years (e.g. Gwynne et al. [11]). Since then, more authoritative reviews have been conducted – the most influential being those conducted by Kuligowski et al. [12], [13]. This later work very much builds on the early model reviews and examined a wider set of contemporary models.

Broadly speaking, these reviews examined the following model capabilities (of relevance here)[2]:

- Representation of the building
- Representation of the population
- Representation of evacuation behaviour / response
- Representation of the environmental conditions
- Results and insights that are generated
- Confidence in the model performance.

The capabilities of the available models have been examined to establish that they can represent the scenarios of interest. Effectively, the models have been reviewed to determine their:

- Availability (either to the public or to the authors);
- Capacity to represent key evacuee behaviours including route selection, pre-evacuation delays, variation in movement/flow rates that might be achieved, and evacuee objectives;
- Capacity to reflect different population types (including those with movement impairments);
- Capacity to represent the scale and type of building outlined;
- Representation of terrain and transitions present within these structures;
- Representation of either global (flow) and individual evacuee perspectives (i.e., the two models selected adopt different perspectives);
- Generation of output on the performance of the population within locations of interest, floors, individual stairwells, building wide. This output reflects route use, arrival times, distances travelled, and congestion experienced; and
- Availability of model testing documentation.

[2] Many other aspects were addressed, for instance the inclusion of fire conditions. However, as these will not be directly addressed in this work, they are omitted here.

Kuligowski et al.’s review [13] explicitly addresses these criteria. In their work, they developed a series of model performance levels within each category allowing the reviewer to establish model capabilities. A set of performance levels have been identified (i.e., lower bounds) to ensure that the two models meet the requirements for the two stages of this project. Using Kuligowski et al.’s criteria, this means:

- Availability - (Freely available or commercially available and accessible)
- Perspective – (Global / Macro or Individual / Micro)
- Behaviour – (Either Implicit, Conditional or Probabilistic)
- Movement – (Density-based or User Defined)
- Visual – (2D or 3D)
- Validation – (minimum of comparison against fire drills, past experiments, and other models).

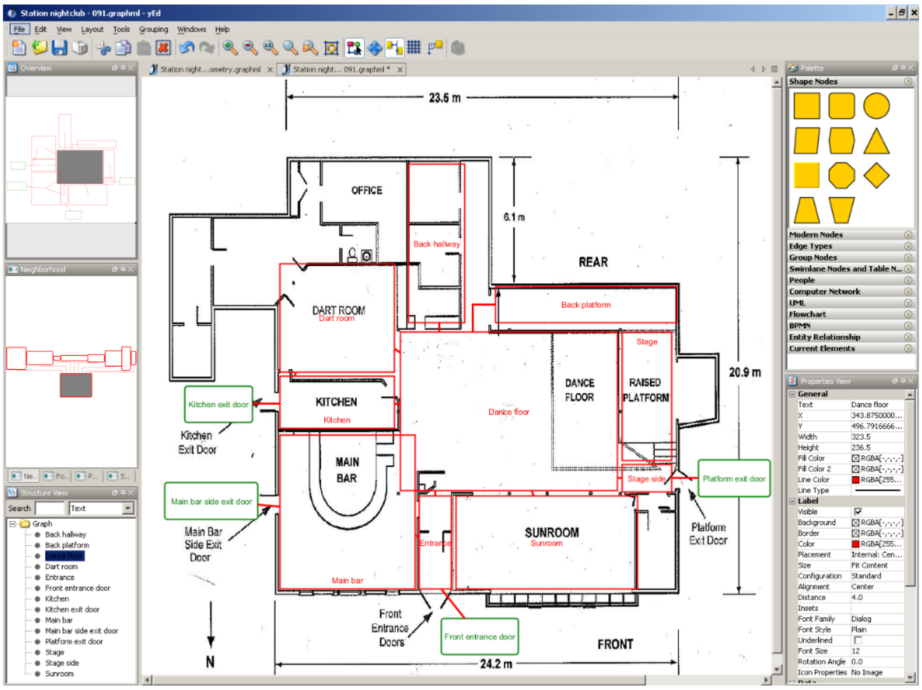
From reviewing the models identified by Kuligowski et al. (and from examination of recent model releases), several candidate models have been identified as meeting these requirements. The models selected from these candidates for use are:

- **Model A**: Evacuationz (evacuationz.wordpress.com/); and
- **Model B**: Pathfinder (www.thunderheadeng.com/pathfinder/).

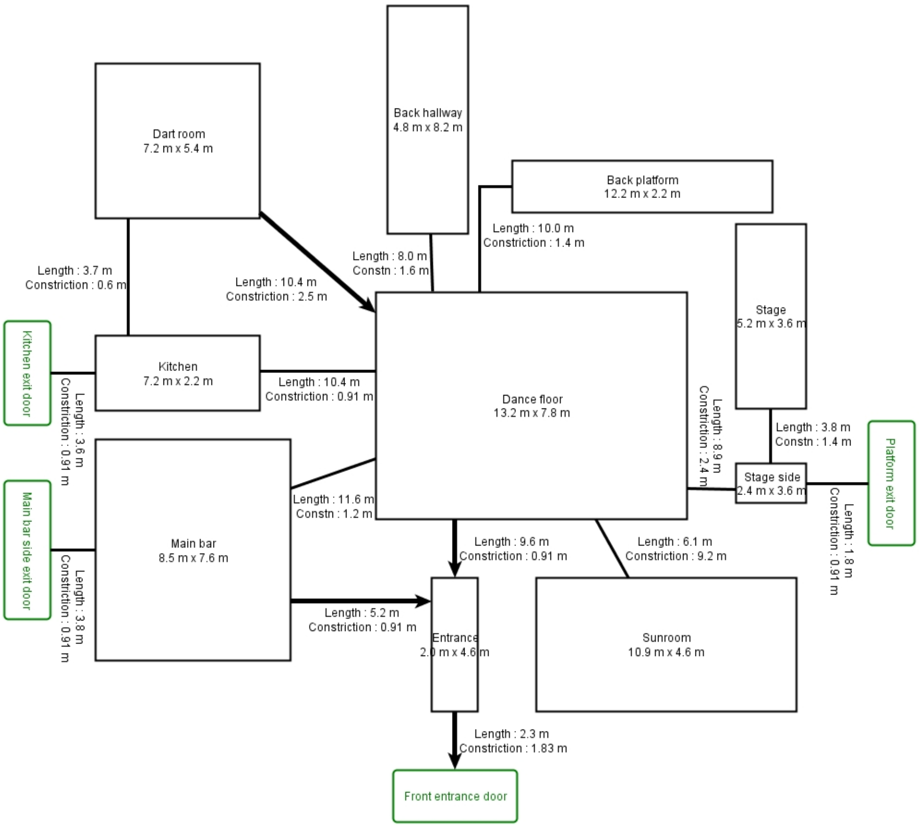
Both models meet the criteria identified above, are available to the authors for use in this project and adopted different perspectives allowing the Stage 1 and Stage 2 analysis outlined and the necessary comparison between the results generated from different perspectives, i.e., flow-based evacuee movement and simulation of individual evacuee movement.

A2-4.2 Evacuationz

Evacuationz employs a coarse network approach to represent a building to reduce computational times allowing for many repeated runs to be completed in a relatively short time. Spaces are described by a network of nodes which are connected together by paths. Nodes are defined in terms of length and width dimensions and connections are defined in terms of their length and other characteristics (Figure A2-4. Rooms, corridors, refuge areas, stairs, doors etc. can be described by an appropriate combination of nodes and paths.



(a)



(b)

Figure A2-4 Network representation of The Station nightclub(taken from ref. [14]): (a) Using a software tool to overlay the network on the building plan; (b) Expanded network diagram showing node dimensions; connection lengths and constriction widths, and the preferred exit route indicated by bold arrows

People are represented as agents, each with their own behavioural and personal attributes. Pre-evacuation times can be represented through the use of distributions with the shape and statistics appropriately selected by the user. A network has to have one or more ‘safe’ nodes which represent final destinations for agents. Simulations are run over a defined time period or until all agents have reached a ‘safe’ node. The model includes a range of exit behaviour strategies including those that require the minimum travel distance to any ‘safe’ node, the minimum travel distance to a user-specified ‘safe’ node, those paths that are preferred by the agents and can also respond to levels of congestion. The choice of exit behaviour can be probabilistically assigned to groups of agents.

Movement in crowded conditions is based on the equations provided by Gwynne and Rosenbaum [15] such that the relationship between speed of travel and occupant density is given by a linearly decreasing function for occupant densities greater than 0.5 persons/m^2. Uncongested movement speeds can be fixed by the user or determined by the use of a distribution. The model also accounts for the effect of queues at constrictions using the effective width concept. The formation of a queue will depend on the presentation rate at the constriction, and it is possible that no queue will form. Movement can be affected by the presence of smoke and/or reduced lighting conditions.

The model has the ability to employ a range of distribution shapes whenever stochastic input parameters are used. Distributions can be in the form of a mathematical function or a user-defined frequency description. The model generates output files at the building and individual level and can also generate 2D or 3D animations.

The software is publicly available but also the developer is one of the project team which allows new functionality to be added if necessary. The tool has also been subject to a range of verification and benchmarking studies [14], [16]-[17].

A2-4.3 Pathfinder

Pathfinder is an agent-based egress simulation model. The evacuating population is represented as a set of individual agents defined by attributes attached to each individual which either affect performance during the simulation or reflect the conditions faced. It employs a combination of steering behaviours and physical constraints to simulate evacuee response and generates evacuation times based on the movement and interaction of these agents. Agents may be assigned delays to reflect their expected activities during (or before) the evacuation, may choose to use different routes out of a structure, and may exhibit various characteristics that affect their performance. This allows a range of different behaviours and outcomes to be represented including counter-flow, blocked exits, group behaviour (with specific reference to those using evacuation devices), individuals with movement impairments and the use of lifts.

The model can represent complex spaces, described by building information models (BIM) or more traditional CAD formats. This detail is particularly useful given that Pathfinder represents movement on a continuous plane located at each floor level (and between). The model calculates movement across these planes using a triangulated mesh to represent occupiable space and then the paths across it. This movement can be left to individual encounters or be driven to conform to SFPE performance levels (enabling the SFPE performance assumptions to be imposed on the simulation process if need be). Agents can react to their perceived surroundings, e.g., the congestion encountered. This may lead to them redirecting should other routes be available. The model is able to generate agents during the simulation (e.g., representing the arrival of a train, or responders) and can import fire data from the Fire Dynamics Simulator (FDS) computational fluid dynamics tool (although this functionality will not be used in this project).

The model produces 3D output (Figure A2-5), contour plots, level of service maps and CSV files including the array of outputs at the individual, population and building levels along with functionality allowing the user to manage the output produced.

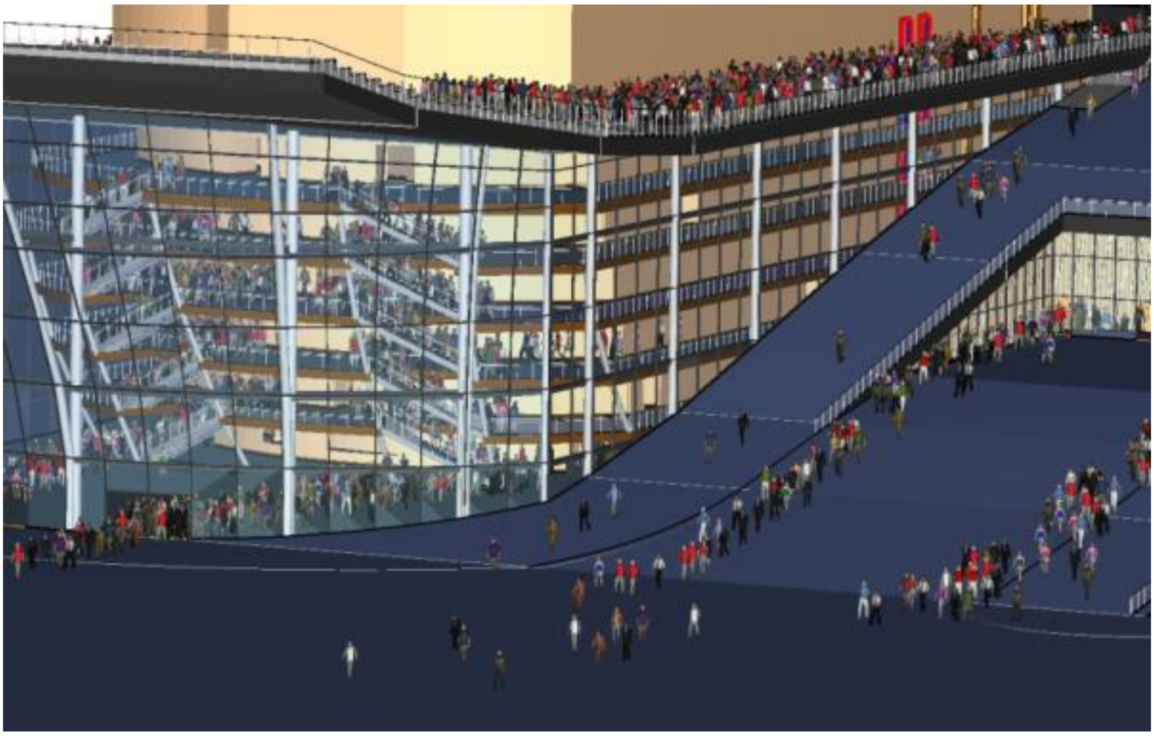


Figure A2-5 Example Pathfinder output (from Thunderhead website: www.thunderheadeng.com/pathfinder/pathfinder-features/)

The software is commercially available and is commonly used within fire safety engineering design. Examples of previous research that has used Pathfinder includes those of Ronchi and co-workers [18], [19]. It is also understood that

Pathfinder will be used by the UClan-led team as part of the Home Office element of this project.

Given the refinement at which each software tool operates and the associated computational cost in running each scenario, a two-stage approach will be adopted to the scenarios identified in Section A2-5:

- Stage 1: Evacuationz will be applied to the complete set of scenarios required. The results from the Evacuationz simulations will be interrogated to identify a small sub-set of scenarios where key indicators change noticeably and warrant further investigation.
- Stage 2: Pathfinder will be applied to further investigate the sub-set of scenarios identified at Stage 1 in more detail (e.g., reflecting key conditions, stress-testing designs in a critical manner, etc.).

A2-5 Scenario development

A2-5.1 Scenario matrix

Table A2-2 identifies the various input parameters that are to be considered for the modelling scenarios. The parameters have been split into six main categories which are then further divided into sub-categories. Each sub-category is then assigned between two to four levels that will be adopted within the modelling application. One of the four levels will serve as a baseline case. In essence, a value for each of these parameters will be identified and then the combination of these values will produce the set of scenarios examined.

Using the previous work discussed in **Objective B2** and where appropriate additional review of research and guidance literature, each sub-category includes its potential impact on the evacuation process. Specifically, the parameters may increase (↑) or decrease (↓) pre-evacuation (P-E) times, travel speeds (TS), achievable flow rates (FR), efficiency of route use (RU) and/or route availability (RA). Further details on each parameter are presented in Section A2-5.2. Multiple arrows indicate more significant impact on the response component.

In developing the scenarios those factors that are relevant to guidance within ADB are identified. The impact of these factors will be explored in conjunction with other factors that are not directly addressed by current guidance. This allows the work to assess the expectations set by ADB and what responses might be anticipated when these factors are set.

Table A2-2 Summary scenario matrix

Parameter		Option A	Option B	Option C	Option D
Event parameters					
1e	**Time of day**	Day	Evening	Night	-
	Impact on Response	*Baseline case*	*Baseline*	P-E↑↑	-
2e	**Weather Conditions**	Pleasant	Inclement[3]	-	-
	Impact on Response	*Baseline case*	P-E↑ TS↓	-	-
3e	**Fire location**	Lower	Mid	Upper	-
	Impact on Response	Population potentially affected by fire and evacuation procedure			

[3] To the extent that an individual may either need preparatory actions to protect themselves against the conditions and/or hesitate before moving into the conditions.

Parameter		Option A	Option B	Option C	Option D
4e	**Fire impact**	Flat of origin (FToO)	Floor of origin (FRoO)	Stair	-
	Impact on Response	*Baseline case* TS↓↓ (FToO) P-E↓↓ (FToO)	TS↓↓ (FToO/ FRoO) RA↓ (FToO/ FRoO) RU↓ (FToO/ FRoO)	TS↓↓ (FToO/FRoO/ AdjStair) RA↓ (FToO/FRoO/ AdjStair) RU↓ (FToO/FRoO/ AdjStair)	-
Building parameters					
1b	**Building height**	11 m 4 levels	18 m 6 levels	30 m 10 levels	170 m 51 levels
2b	**No. of Stairs**	One	Two	-	-
	Impact on Response	*Baseline case*	RA↑	-	-
3b	**Stair width**	1 m (1.1 m for heights > 18 m)	1.5 m (1.6 m for heights > 18 m)	2.0 m (2.2 m for heights > 18 m)	-
4b	**Corridor length**	7.5 m	30 m	-	-
5b	**Amenity spaces**	Lower	Mid	Upper / roof	-

Parameter		Option A	Option B	Option C	Option D
Procedural parameters					
1p	**Means of warning**	Local sounder	Global sounder	Global voice	-
	Impact on Response	*Baseline case* P-E↑ (on same floor – not directly exposed to sounder) P-E↑↑ (elsewhere)	P-E↓	P-E↓↓ RU ↑	-
2p	**Evacuation lift**	No	One	Two	-
	Impact on Response	*Baseline case*	RA↑ RU↑ OT↑	RA↑↑ RU↑↑ OT↑	-

Parameter		Option A	Option B	Option C	Option D
3p	**Evacuation strategy**	Stay put	Clustered	Phased	Simultaneous
	Impact on Response	*Baseline case* P-E (FToO)	P-E (Representation of impact of notification system and incident cues on response by resident location)	P-E (1st phase – Preparation and Decision-making) P-E (2nd phase – Decision-making)	P-E = 0
Occupant parameters					
1o	**No. of residents**	*Baseline case* Maximum	Distribution	-	-
2o	**No. of visitors**	*Baseline case* Maximum	None	-	-
3o	**Demographics**	Optimistic	Representative	-	-
	Impact on Response	*Baseline*	P-E↑ TS↓	-	-

Parameter		Option A	Option B	Option C	Option D
4o	**Population location**	In flats	Flats / amenity spaces	-	-
	Impact on Response	*Baseline*	No occupant in communal space will be asleep (P-E↓) OT↑ (e.g., return to flat)	-	-
		Affects sub-populations exposed to smoke conditions and evacuation procedure.			
FRS parameters					
1f	**FRS attendance**	Not yet arrived / Not affecting evacuation	Yes – Arrived and in building stair[4]	-	-
	Impact	None	RA↓ FR↓ P-E ↓	-	-

[4] FRS attendance during the ongoing evacuation.

Parameter		Option A	Option B	Option C	Option D
Occupant response parameters					
1r	**Pre-evacuation** **(P-E)**	None	Set distribution	Derived assuming that behaviour is affected by scenarios factors as described above.	-
2r	**Travel speed** **(TS)**	Maximum	Set distribution	Derived assuming that behaviour is affected by scenarios factors as described above.	-
3r	**Route available** **(RA)**	All	Affected by factors	-	-
4r	**Route use** **(RU)**	Nearest	Familiar	Derived assuming that behaviour is affected by scenarios factors as described above.	-
5r	**Occupant tasks** **(OT)**	None	Specified	-	-

Parameter		Option A	Option B	Option C	Option D
6r	**Achievable flow rate** **(FR)**	Baseline	Derived assuming that behaviour is affected by scenarios factors as described above.	-	-

TS – Travel speed; RA – Route availability; RE – Route efficiency; P-E – Pre-evacuation; RU – Route use;
OT – Occupant tasks; FR – Flow rate

FToO – Flat of fire origin; FRoO – Floor of fire origin; AdjStair – Adjacent to stair

A2-5.2 Parameters

This section provides details for each parameter identified in the scenario matrix in Table A2-2. When using these parameters to define scenarios, not all combinations represent realistic real-world conditions and can therefore be omitted (see Section A2-6).

A2-5.2.1 Event parameters

1e. Time of day

There are three options, i.e., day, evening, and night, identified for this parameter which cover the full span of time an occupied building is in use. The delineation of time of day is intended to capture the potential difference in behavioural response of the occupants and the number of residents / visitors in the building (see Section A2-5.2.4, occupant parameters). In addition, in some scenarios evening will be linked with a maximised amenity space use.

The day and evening times will be associated with the selection of a pre-evacuation response profile with relatively shorter response times due to occupants likely being awake. Whereas for the night-time case, a pre-evacuation response profile with relatively longer response times will be adopted.

2e. Weather

Weather may impact the willingness of occupants to evacuate a building [20]. If they should decide to evacuate, then there is the additional time to don extra clothing [21] the movement of occupants may be slowed by additional clothing they may decide to wear; the space occupied by each individual may increase, e.g. Table 2 of ref. [22]; and the ability of people to travel along exposed routes such as outside balconies and stairs [23] may be affected. For the purposes of this study, it will be assumed that all evacuation occurs inside the building and thus there is no additional impact on travel speed over and above the slowed movement due to additional clothing. To capture the additional time needed to prepare for evacuation especially at night and in the winter, an extra delay in response times will be included, for example using the work of Rinne et al. [24].

3e. Fire location

Fire location is defined at three positions corresponding to the three divisions of each exemplar building, i.e., lower, mid and upper. The location of the fire will relate to the extent of smoke spread, particularly in relation to the stairs. The floor of origin associated with each of the three divisions will be determined in conjunction with survey responses from the work that is being carried on in **Objective B2** (as part of **Task B2.4**).

4e. Fire impact

The precise scale and severity of a fire will vary widely between buildings and across fire scenarios. Therefore the fire dynamics will be aggregated into three impact levels with increasing consequence. A fire at the first impact level only affects the flat where it originated (FToO). This represents a mild incident which triggers an evacuation response, but it has yet developed into a severe incident that would affect any other area of the building and reduce individual evacuation performance.

The second impact level will have smoke spread from the flat where the fire originated into the corridor on the same level (FRoO). This represents a moderate incident which may hinder the evacuation of residents that utilise the corridor.

The last impact level represents a severe incident. Part of the evacuation route may be compromised due to the fire and smoke or the effect of smoke hinders the evacuation, slowing down occupants (AdjStair). The smoke may spread into the whole corridor and the adjacent stairwell, resulting in untenable conditions within the stairwell.

For the modelling, the impact of the fire and smoke will be captured in one of two ways: either occupant evacuation is hindered, or evacuation is prevented. The former will be captured by adopting a reduced travel speed of 0.3 m/s in smoke affected areas equivalent to a smoke extinction coefficient of 0.5 m^{-1} [25] and for the latter, the evacuation routes will become sufficiently smoke-affected to be deemed impassable [26]. The fire severity is therefore applied in the form of Table A2-3.

Table A2-3 Hinderance and compromise categorisation.

	Hinder	Compromise
Flat	H1	C1
Corridor	H2	C2
Stair	H3	C3

where each ‘H’ or ‘C’ category is assigned an appropriate representative time.

As an example, to define the ‘H’ or ‘C’ elements Proulx et al. [21] state

> “*Most fire scenarios predict that a fire that has burned free for 10 minutes emits quantities of smoke, heat and toxic gases that can impede egress. Suite separations will usually provide a means of fire containment for a period of time of typically 10 to 20 minutes. After that, it may be difficult for occupants on the fire floor to leave their apartments. Doors accessing exit stairwells will usually provide 20 to 30 minutes of fire protection to occupants in the stairwells unless occupants’ movement and fire suppression activities allow smoke to propagate into them*.”

The above might suggest H2 be assigned a value of 10 min and H3 be assigned a value 20 min, and then C2 be assigned a value of 20 min and C3 be assigned a value 30 min. In the incident reported by Proulx et al. [21] they found that many occupants who attempted escape around 9 to 10 min after the building alarm was raised were still able to use the common corridor leading to a stairwell even though smoke was present. However, some people decide to turn back at some later stage because of the smoke conditions.

In the case of the flat of fire origin, p. 2394 of the SFPE Handbook suggests that "...*even the most rapidly growing flaming fires take approximately 3 min to reach levels of heat and gases hazardous to life*…" which might point towards C1 being 3 min. It is important to note though that there is not necessarily an expectation that occupants in the flat of fire origin will have sufficient time to escape. In the incident reported by Proulx et al. [21] one of the two occupants of the apartment of fire origin died 2½ months after the incident.

A2-5.2.2 Building parameters

1b. Building height

Four building heights, 11 m, 18 m, 30 m and 170 m are proposed for the exemplar buildings to align with relevant ADB guidance trigger heights or selected to capture taller buildings (see Section A2-2.2). As these are trigger heights (i.e., additional measures are recommended above these height thresholds), the modelled heights will be marginally below the heights in Table A2-4 to ensure the different requirements are captured. The corresponding number of floors have been calculated with a representative storey height of c. 2.75 m to maximise the number of floors in each case. This value has been selected based on the technical requirements identified in the nationally described space standard [27] which requires that the minimum floor to ceiling height is 2.3 m. An allowance of 0.45 m has been made for the build-up between the ceiling and floors.

Table A2-4 The number of storeys for each building height (based on a storey height of c. 2.75 m)

1b. Building height	Up to 11 m	Up to 18 m	Up to 30 m	170 m
No. of storeys	4	6	10	51*

* No. of storeys quoted for the proposed building in London [4].

2b. Number of Stairs

While single stair high-rise residential buildings can be considered to pose a higher risk to occupants (when compared to buildings with multiple stairs), for completeness, this project will also consider a building with two stairs. This is the minimum expectation for high-rise residential buildings over 18 m in Scotland [3] and may also form part of the guidance in an upcoming revision to BS 9991 ‘Fire safety in the design, management and use of residential buildings – Code of practice’.

3b. Stair width

There are three options for stair width as noted in Table A2-2. The first width corresponds to the minimum width of an escape stair which, when the stair is not a firefighting stair, is 1,000 mm (taken as the minimum acceptable width for everyday use from Approved Document K [28]). This increases to 1,100 mm where the stair is used for firefighting purposes, per ADB. Whether the stair is used for firefighting purposes typically depends on the building height, with firefighting stairs recommended in buildings with a storey above 18 m.

The second width option considers an additional 500 mm stair width (i.e., 1,500 mm for non-firefighting stairs and 1,600 mm for firefighting stairs). This is to correlate with a recommendation within BS 9999 (as limited information on this item is provided within ADB or BS 9991) where it is anticipated that counterflow with escaping occupants and firefighters entering the building may occur.

The final stair width option is double the width of the first option (i.e., 2,000 mm for non-firefighting stairs and 2,200 mm for firefighting stairs) to simulate an equivalent unrestricted counterflow between escaping occupants and firefighters utilising the stair.

4b. Corridor length

Two corridor lengths are considered as noted in Table A2-2 and discussed in Section A2-2.1. The first option, 7.5 m, corresponds to the maximum single direction travel distance limit from a flat entrance door to a common stair or stair lobby as recommended in ADB. The second option, 30 m, considers the maximum single direction travel distance limit recommended in PD 7974-5 [29], irrespective of smoke control systems, sprinklers, etc., to account for firefighter physiology.

For the longer corridor option, an additional seven flats will be incorporated at either side of the floorplate, resulting in twenty-one flats per floor. The resident population will increase accordingly.

5b. Amenity spaces

There are three options for the location of amenity spaces as noted in Table A2-2. These are either lower in the building (e.g., at ground floor) where merging flow at the final exit may be a factor, mid or upper / roof. The latter two options will see a greater utilisation of the escape stair(s). Although architecturally unrealistic, for simplification in the modelling, and to retain a consistent number of residents, the amenity space will be appended to the floorplate of the building.

A2-5.2.3 Procedural measures

1p. Means of warning

There are three options for means of warning as noted in Table A2-2 and discussed in Section A2-2.3.2. These are local sounder, global sounder and global voice – each of which has a certain coverage and capacity to provide a particular signal or message. The means of warning will affect the number of occupants with knowledge of the incident, the information that may be available to them, and therefore, their pre-evacuation time – the time before they start to move to a place of safety.

2p. Evacuation lift

There are three options for evacuation lift (see Table A2-2). The inclusion of one or two evacuation lifts increases route availability, particularly for those with mobility impairments. The third option is that no evacuation lift is available. The simulation scenarios will be configured not to use any lift or use one or two lifts during the evacuation, corresponding to the three options for this parameter.

For the convenience of modelling the buildings in Pathfinder, space enough for two lifts will be reserved for each exemplar building even if the lifts are not present. Depending on the space reserved, the capacity of each lift car will be taken to be equivalent to that given by Strakosch and Caporale in 'The Vertical Transportation Handbook' (Table A2-5) as quoted by Watson [30].

Table A2-5 Standard lift car sizes and achievable loadings in tall residential buildings, taken from Watson [30]

Capacity		Car Inside (mm)		Observed Loading
Kg (lb)	Wide	Deep	Area (m^2)	(People)
1200 (2640)	2100	1300	2.73	10
1400 (3080)	2100	1450	3.05	12
1600 (3520)	2100	1650	3.47	16
1600 (alt.)	2350	1450	3.41	16
1800 (3960)	2100	1800	3.78	18
1800 (alt.)	2350	1650	3.88	18
2000 (4400)	2350	1800	4.23	20

The proposed building geometry can be configured to have sufficient floor area to include lift cars with a capacity of 9 people (similar to a building one of the authors lives in). However, smaller cars with a capacity of 6 people are available from suppliers and consideration as to whether the lift should be represented with this capacity needs to be made.

3p. Evacuation strategy

Four evacuation strategies are considered: stay put, clustered, phased, and simultaneous. These options have been selected to capture a range of occupant responses and is linked to procedural parameter 1p (means of warning) and FRS parameter 1f (FRS attendance).

Stay put is the commonly adopted evacuation strategy for residential buildings, whereby the high level of compartmentation between dwellings should mean that only the flat of fire origin (FToO) needs to be evacuated unless occupants in other flats felt they needed to also evacuate for some reason. For this option, only a local alarm will have sounded. For the simulations it will be assumed that only occupants in the flat of fire origin need to evacuate.

Clustered evacuation is included to capture the impact of external cues on an individual's initial response. These external cues will include the notification system in place (given its coverage and message), exposure to cues generated by the fire, the actions of other residents, and any impact on behavioural response by the FRS. Exposure to these cues will be dependent on occupant location, information they receive, etc. This will be represented by a certain percentage of the occupants deciding to escape. The clustered evacuation will therefore consider situations in which occupants remote from the flat of fire origin decide to evacuate for whatever reason. The simulations will examine a range of scenarios in which different percentages of the building occupants other that the occupants of the flat of fire origin decide to evacuate (for example, 25% in one scenario, 50% in another scenario, etc.). As such, the stay put strategy is equivalent to a 0% evacuation case, and the simultaneous strategy is equivalent to a 100% evacuation case. Results from these simulations will be benchmarked against the findings of the occupant survey work that is being carried on in **Objective B2**.

Phased evacuation represents an attempt to manage the evacuation. For instance, those most at risk (e.g., the floor of fire origin and floor above the floor of origin) evacuate first, followed by the next floors, above/below the floor of origin, and finally the rest of the building. The precise procedural approach will be sensitive to the building design and will be outlined in detail in the reporting of the model configuration. However, the expectation is that not every possible phased evacuation procedure will need to be simulated and indicative scenarios, such as the fire floor and the one above procedure, will be sufficient to draw meaningful findings.

Finally, the simultaneous evacuation strategy is where all building occupants prepare to leave the building at the same time. Depending on the pre-evacuation distribution selected this could mean all occupants move at the same time, or movement may be staggered over a range of times.

A2-5.2.4 Occupant parameters

1o. Number of residents

The number of residents will be estimated using the two methods described in Section A2-3.1.1. In addition, a maximum occupant number will be obtained using the equivalent guidance given by ADB.

2o. Number of visitors

Visitors will be placed in the amenity space. Two levels will be applied: no visitors and the maximum allowed number of visitors for the amenity space – 110 people (see Section A2-3.1.2). This parameter will be linked with event parameter 1e (time of day).

3o. Demographics

Population demographics will affect the set of attributes (physiological, social, experiential and psychological) that make up each resident. Two levels are proposed for this parameter (see Table A2-2). 'Optimistic' is where it is assumed all occupants have the same maximum uncongested walking speed of the 'standard' value of 1.2 m/s. This employs the baseline pre-evacuation distribution (i.e. has no impact on it). The alternative ('Representative') population will use age and sex profiles for the UK / England. The walking speed profile will be derived based on current UK age distributions and also the proportion of these who have a movement impairment. The second approach would also include the speed of mobility impaired persons as a sub-group. This parameter will be linked with parameters 1o (number of residents) and 2o (number of visitors).

As noted previously, demographic data for the UK population derived from the 2011 Census is available from the Government.

4o. Population location

Residents will either be in their flats, or in their flats and in the amenity space. Where the number of visitors in the amenity space is maximised (see parameter 2o, number of visitors) then residents will be assumed to be in their flats. Where visitor numbers in the amenity space is less, then residents could be either in their flat or using the amenity space.

A2-5.2.5 Fire and rescue service parameters

1f. FRS Attendance

Attendance of an FRS would likely affect the capacity of stairs and could also have an impact on the behavioural aspects associated with evacuation.

Two levels of FRS attendance will be examined. Firstly, the FRS will not be in attendance (or at least not yet in the building and affecting the evacuation). This might represent the period before the FRS is on site, but during which the evacuation has commenced or where they are on site but have not yet entered the building.

The second level assumes that the FRS are on site and inside the building. The primary impact of this is that the FRS will either commandeer an entire stair (reducing the routes available), or (if only a single route is available) bidirectional flow on a stair will be assumed with the capacity of the stair split between ascending FRS and descending occupants. The impact on the behavioural aspects associated with evacuation are addressed in parameter 3p (evacuation strategy).

It will be assumed that the number of FRS personnel in attendance will not have an impact of either the stair capacity or the evacuation procedures. In addition, it is not within the scope of this research to consider the physical attributes of FRS personnel (such as stair climbing speeds, see Claridge and Spearpoint [31] for example) nor the precise tasks they will carry out to tackle the fire to aid resident evacuation. There is a parallel research project commissioned by the Home Office that is investigating FRS operational procedures in high-rise residential buildings.

A2-5.2.6 Occupant response parameters

1r. Pre-evacuation

There are three levels examined for this parameter (see Table A2-2). The first level, None, means no pre-evacuation behaviour will be represented and the resident population will respond immediately to the evacuation request. The second level, Set Distribution, means that representative pre-evacuation delay statistics will be derived from the literature e.g., PD-7974 / SFPE handbook and modelled.

Baseline pre-evacuation mean values (see Table A2-6) have been derived based on status (whether an individual is awake or asleep) and level of impairment (whether an individual has an impairment or not).

Table A2-6 Baseline mean pre-evacuation times for residents based on status and impairment

Level of impairment	Status	Implied Pre-Evacuation Time (s)				
		Voice	Tone / bell	Person	FRS	Smoke Cues
Impaired	Asleep	300	600	300	240	240
	Awake	180	300	180	120	120
Unimpaired	Asleep	180	360	180	120	120
	Awake	90	180	90	60	60

The research literature often suggestions that a skewed distribution such as log-normal or Weibull is appropriate to represent pre-evacuation. The challenge with these shapes is that they mathematically extend to infinity and therefore can present some computationally intricacies. One solution is to truncate the functions, but another is to use a triangular distribution with characteristics that provide a reasonable match to a log-normal or Weibull shape. A previous evacuation modelling study [32] showed that this approach is reasonable and so it will be adopted in this project.

The third level, derived pre-evacuation, is where the specific conditions represented within the scenario are coupled with the procedure employed (see 3p, evacuation strategy), the risk perception research conducted in this project and the baseline pre-evacuation distributions.

2r. Travel speed

Travel speeds will either be set to (1) maximum expected travel speeds, (2)a representative distribution of speeds for residential evacuees given the demographics represented, or (3) be derived from the scenario conditions faced given the environmental, procedural and demographic attributes present within the building. The unimpeded walking speed distributions for different age ranges (see parameter 3o, demographics) given by Lord et al. [33] will be adopted in the simulations.

Provisional baseline travel speeds have been derived from the research literature and guidance available, as reported for Objective A1. Example values for horizontal and vertical travel speeds are shown in Table A2-7.

Table A2-7 Baseline travel speeds

Direction	Speed (m/s)
Horizontal	1.20 ± 0.20
Vertical	0.70 ± 0.20

These values might be modified for sub-populations with movement impairments (see Table A2-8).

Table A2-8 Baseline speed modifiers due to impairment

Direction	Multiplier
Horizontal	0.50
Vertical	0.40

The precise nature of the distributions employed for these speeds will likely be modified for the scenarios examined and within the building spaces represented.

3r. Route available

Route availability might be reliant on the smoke conditions. There has been considerable work (e.g., Purser, Bryan, Wood, as discussed by Kuligowski [34]) suggesting that use of a route is influenced by the reduced levels of visibility produced by the presence of smoke. Given this, this factor will be set to one of the following: (1) all routes are assumed to be available for use, (2) one of the routes out of the building is assumed to not be available given the presence of smoke.

The impact of fire effluent on evacuee well-being will not be modelled – given that the fire itself is not represented. However, where evacuees are deemed to be exposed to smoke conditions then their travel speed will be reduced, as discussed in parameter 4e (fire impact).

4r. Route use

The route use parameter only becomes relevant when there are alternative stairs available to occupants. Route use considers which direction occupants might travel within common corridors based on which stairs (or lift) they might then wish to use. One option is that occupants travel to the nearest stair to their flat entrance. However, an alternative possibility is that one stair is preferred by the occupants during normal daily use and therefore they gravitate to the same stair during a fire. Finally, the choice of stair may be dictated by more complex behavioural factors such as those related to occupant parameters, procedural measures (such as information provided by the notification system in place), etc.

5r. Occupant tasks

In reality, there will be a number of preparatory tasks performed during pre-evacuation (e.g. investigation, communication, searching, etc.). In this analysis, these will be represented within the pre-evacuation delay times. The tasks addressed here will include movement from amenity / communal areas where people are assumed to return to their flats or movement involved in the assistance of other residents with impaired as part of their evacuation. The decision as to whether these tasks will be represented explicitly or implicitly (e.g., through the inclusion of an additional delay) will be documented for each scenario.

The actions of the FRS will also involve movement and might be reflection explicitly within the Pathfinder model. However, given that their impact on the evacuation will be sensitive to their procedure and the precise time of their arrival, their tasks will be reflected primarily by their impact on resident pre-evacuation times and available stair capacity.

6r. Achievable flow

Achievable flow rates can be specified within the models employed. These will likely be used to constrain flow rather than reflect flow conditions expected. As with travel speeds, provisional baseline travel speeds have been derived from the research literature and guidance available (see Table A2-9), as reported for **Objective A1**.

Table A2-9 Baseline flows

Direction	Flow (p/m/s)
Horizontal	0.90 ±0.15
Vertical	0.70 ±0.15

A2-6 Next steps

It is unrealistic to list all possible scenarios and therefore impractical to model each one as part of this project. Therefore, the following procedure will be carried out:

1. Identify all of the combinations within each group of parameters. For instance, there will be 3 x 2 x 3 x 3 = 54 combinations for event parameters. These combinations will be coded in a certain way, e.g., 1eOA-2eOB-3eOC-4eOA means “Day/Inclement/Fire on upper part of the building/Fire affects flat of fire origin”.
2. Select key representative combinations and those of interest within the pool of the parameter combinations.
3. Combine the selected parameter combinations to produce the final pool of simulation scenarios.

The developed parameter combinations of interest will be combined to form a set of scenarios. As described previously, these will be explored in two stages in which Evacuationz will be applied to the complete set of scenarios deemed to be of interest, while Pathfinder will be applied to a sub-set of these scenarios enabling a more refined study to be conducted.

When they become available and where appropriate, results from the parallel resident survey workstream, will be integrated into the selection of the parameters and scenarios.

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