# Development of macroscopic evacuation model for BIM-FSE integration

Vladimir Grachev

Natomas Engineering, Sacramento, USA
SITIS Ltd, Ekaterinburg, Russia
Email: vgrachev@natomaseng.com

## ABSTRACT

A new solver for a macroscopic evacuation modeling was developed. The pedestrian dynamics model solver is based on the fundamental dependencies and properties of pedestrian flows in the works of Predtechenskii and Milinskii, John Fruin and their followers

## INTRODUCTION

BuildingSMART project «Fire Safety Engineering & Occupant Movement openBIM Standards» have held several meetings and webinars were test cases were discussed, and it was mentioned several problems in data exchange - there is a lot of data to be processed in BIM model for occupant movement analysis (OMA).
Currently, there are several examples of applications and technologies for combining BIM authoring and FSE modeling for evacuation simulations. Most of these solutions are based on microscopic pedestrian dynamics models, which results in large volumes of data that need to be stored and accumulated in BIM models.
The idea of the development of macroscopic evacuation model for BIM-FSE integration is:

- the ability to be easily converted from BIM model in BIM authoring software
- relatively small amount of evacuation calculations data to be stored back in BIM model for decision making, visualization and reporting

## PEDESTRIAN DYNAMICS MODEL

Unlike many macroscopic models, in which the movement of pedestrian flows is represented in the form of directed graphs consisting of nodes and edges, in the model the movement of flows is represented as a directed sequence of small 2D regions of the evacuation route, connected to each other at adjacent edges. Such regions can be areas of different type of flows - linear movement of flows, areas of flows intersections and merging, and areas of flows formation of freely moving pedestrians.
This approach makes it possible to simplify development of preprocessors to convert an architectural BIM model into a computational evacuation model, and on the other hand, reduces the amount of data that needs to be stored in the BIM model as simulation results.
Computational model is mainly based on the principles and data from the monographs and research papers:

- V M Predtechenskii «Planning for foot traffic flow in buildings» - main pedestrian flow properties
- SFPE Handbook of fire protection engineering - flow boundary layers
- V A Kopilov «Study of the parameters of people's movement during forced evacuation» - flows with high density and "turbulent" flows
- D A Samoshin «Composition of human flow and parameters of their movement during evacuation» - flows of different type of pedestrians groups (elderly, children, sick, etc)

Basic flow properties in the model are:

- Flow speed is the function from the flow density, type of compartment (corridor, door, stair, etc), width and slope
- Flow properties – maximum flow width in wide spaces, angle of flow extension, angle of flow narrowing
- Flow speed function at areas of flow concentration (doors, openings) must take into account «arch effect», «false opening» effect and similar effects of «turbulent» pedestrian flow
- Flows can have boundary layers. Boundary layer width depends of compartment boundary type (wall, railing) and its height

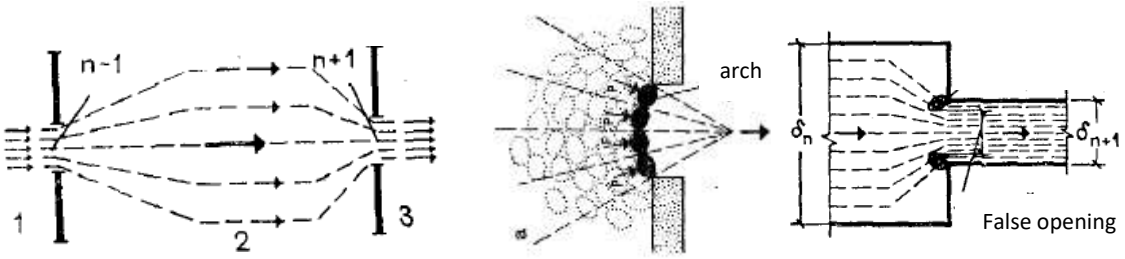



*Figure 1: properties of pedestrian flows, Illustrations from Predtechenskii book (left) flow in wide compartment, (center) arch effect at an opening, (right) false opening effect*

**Evacuation scenarios**

Evacuation scenario in the pedestrian dynamics model – a combination of several model options:

- Tenant distribution and movement start time – tenant groups types, initial tenant number and density in compartments, evacuation start time, etc
- Available exits
- Doors state – open or closed
- Obstructions – existence and locations
- Set of functions speed / density

**Space and time discretization**

Parameter of time discretization - flow calculations time step

Space of the model is represented as a sequence of small fields of flow path from compartments with tenants to exits from the building.

Parameter of space discretization - length of flow path field

There are three types of flow path fields

- Flow formation – freely moving pedestrians, going to nearest exit from the compartment
- Direct flow
- Flow merging

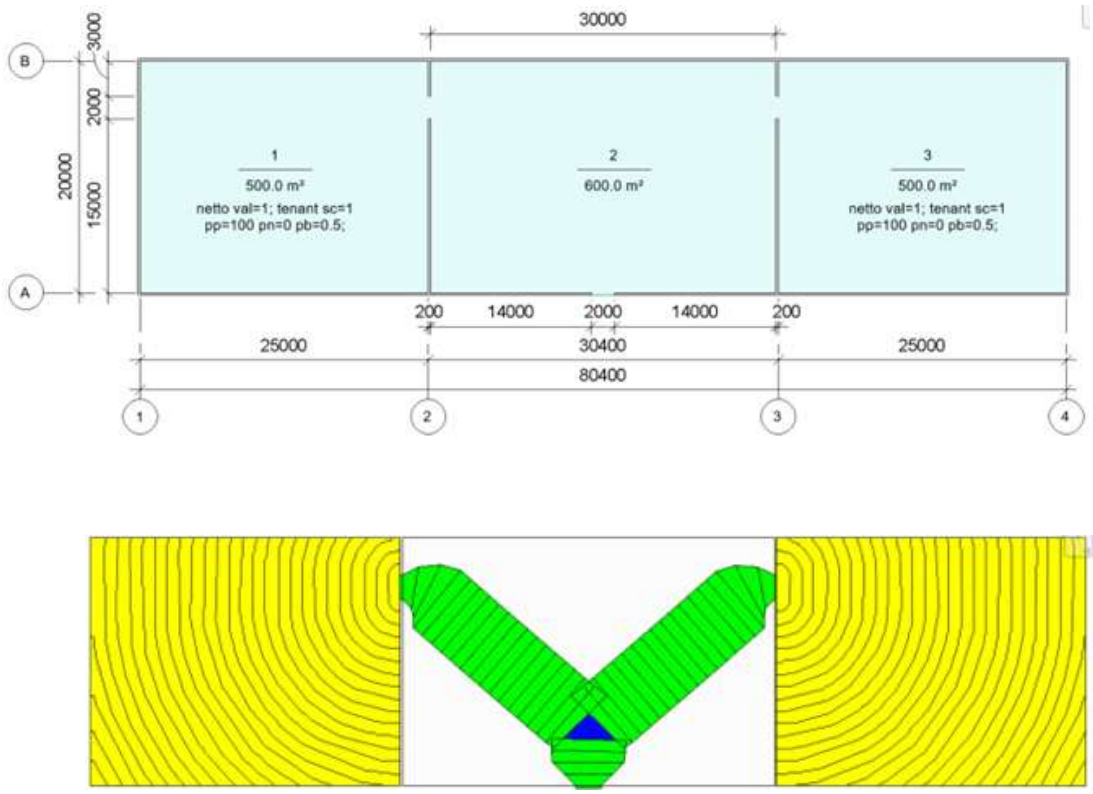



*Figure 2: (top) example compartments layout (bottom) flow path fields. Yellow – flow formation, green – direct flow, blue – flow merging*

## IMPLEMENTATION

The software kit for the applications is a set of codes: add-in for Revit for creating FSE models of buildings from architectural BIM models, a preprocessor for discretizing FSE models into a macroscopic evacuation model, an evacuation simulation solver, a add-in for Revit to import evacuation modeling results into a BIM model and viewing results in the form of diagrams, spatial value fields, PDF and HTML reports.

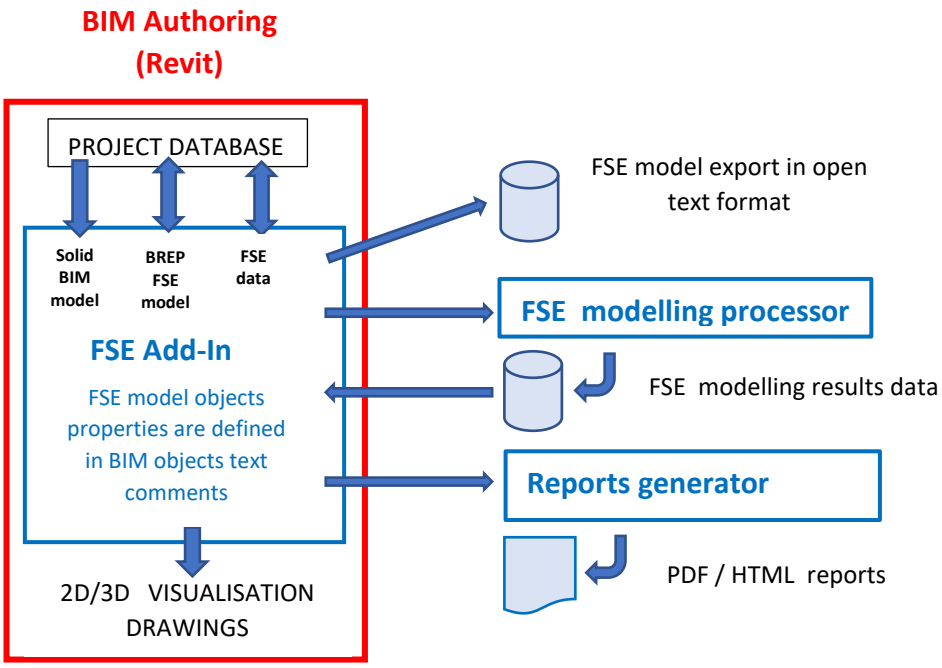



*Figure 3: software application diagram*

FSE model is generated from Revit project database for overall BIM model or a model subset in 3D view window. FSE model is a set of generated simplified objects with BREP (boundary representation) geometry to simplify further simulations in FSE solvers. FSE model objects properties are stored in text form in object comment text string and are available to be read and edited in Revit standard interface dialogs. Special 3D object "Model" is added to FSE model to store parameters and data of hole model. This object is represented as small cube with colored faces in left bottom part of model bounding box.

FSE properties of rooms can be mapped from room names using simple mapping markup language.

For example word «Office» in a room name can be mapped to FSE properties of the room - population density (persons per room area), fire load ( mass or energy per room area), combustible material type and its properties, other data for FSE simulations.

Revit API SpatialFieldView modes "markers", "gradient", "vectors" can be used to visualize data in the Revit interface

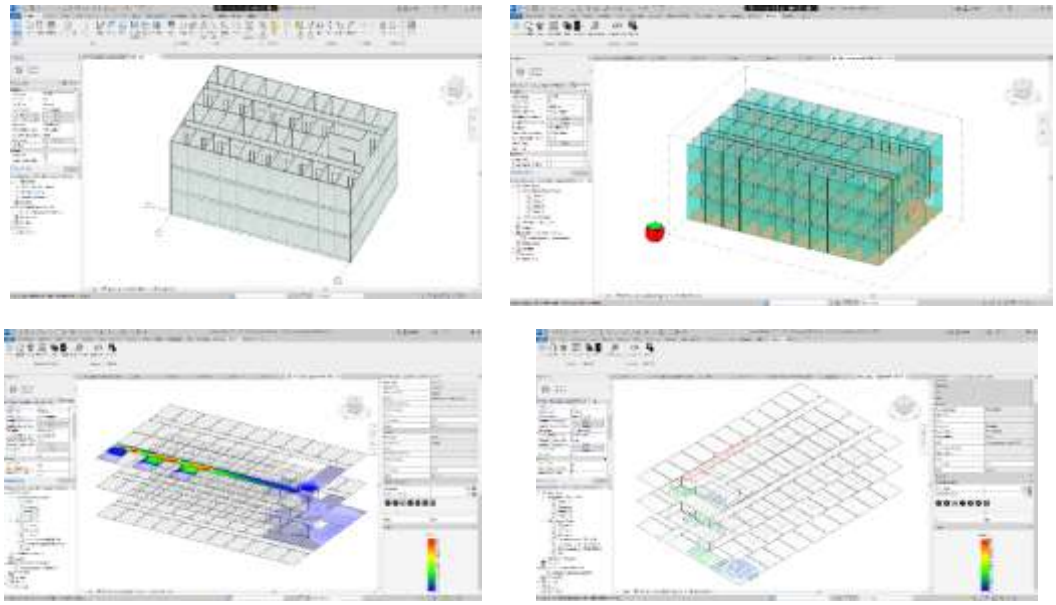


*Figure 4: Revit interface windows, (top left) BIM model, (top right) FSE model, (bottom left) gradient spatial view of evacuation simulations results ,(bottom right) gradient spatial view of evacuation simulations results*

Some other FSE processors for ASET/RSET analysand is fire risk assessment are being developed – convertors to NIST FDS and NIST CFAST models. Also convertor to SimPad, "simulations notepad", is being developed to perform simulation sensitivity analysis and models calibration

## RESULTS AND DISCUSSION

### Verification

To verify the model, analyze the sensitivity of the model parameters and compare it with other models available on the market, a selection of verification benchmarks was made based on test cases from the IMO 1-4, RIMEA, ISO 20414, FDS-EVAC user guide, test case manuals, NCSTAR 1-7 report. A set of fundamental pedestrian flow diagrams from SFPE Guide, DIN 18009-2 and Russian fire risk assessment guidance No. 749 and Predtechenskii book were used for calculations

### Verification models

All test cases are modeled as Revit project as solid BIM models, then converted to FSE models with FSE add-in, and evacuation simulations with developed macroscopic pedestrian dynamic model were performed .

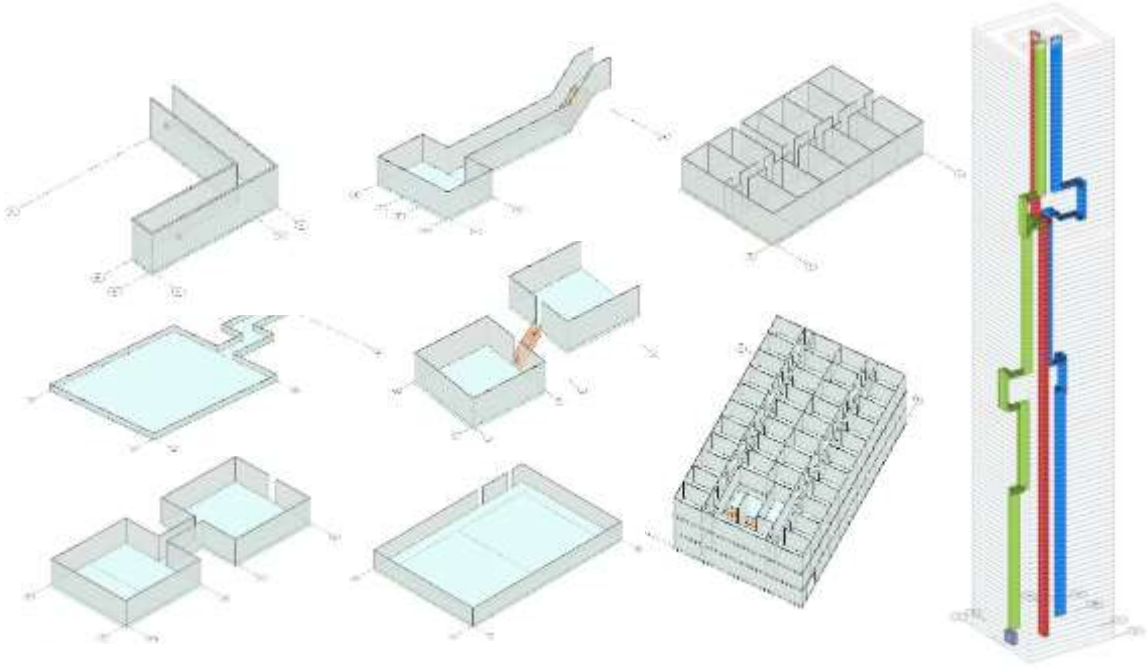


*Figure 5: some examples of verification test cases models*

## Flows speed diagrams

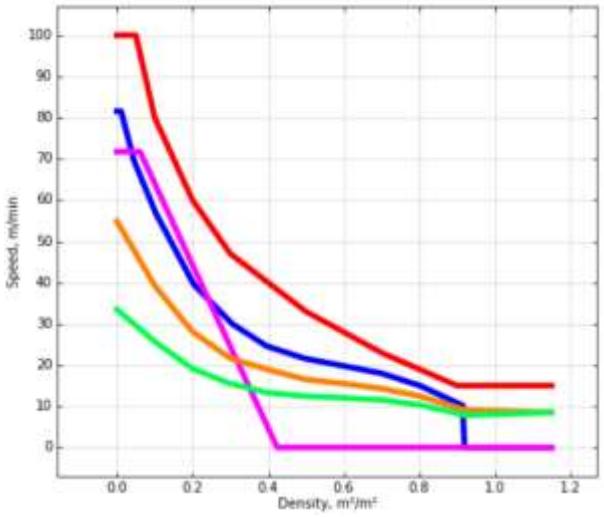
Five sets of fundamental diagrams were used

All functions where unified to be comparable to each other:

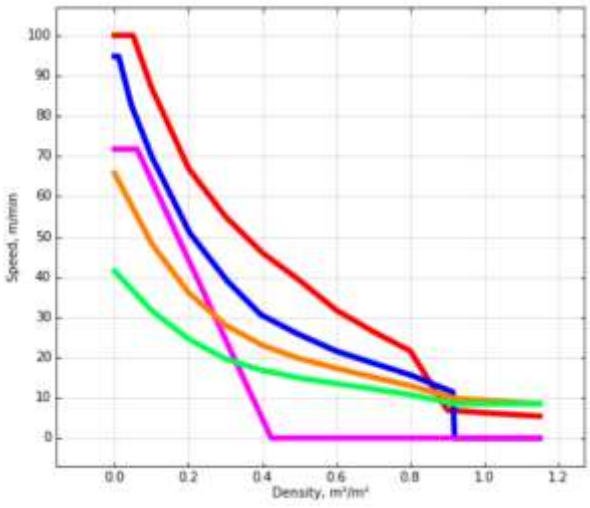
Flow density range is set from 0 to 1.15 m2/m2. If the function is not defined in the literature source at some density, the flow speed is set to 0.0.

Flow density unit is m2/m2, not persons/m2. Person area 1.13 m2/person was taken as conversion factor

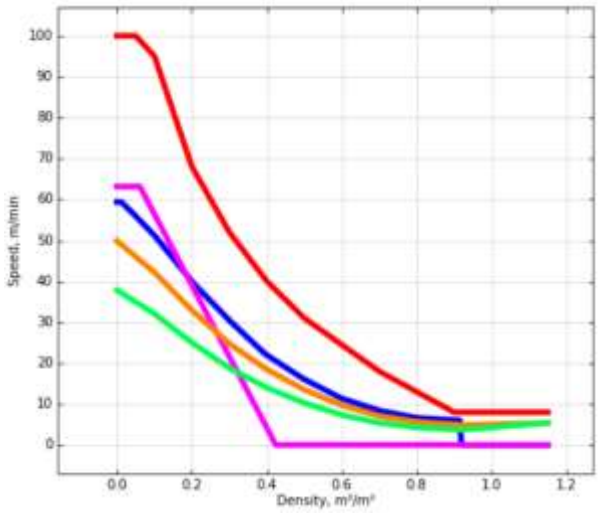
Corridor




Door, 1 m width



Stair down




Stair up

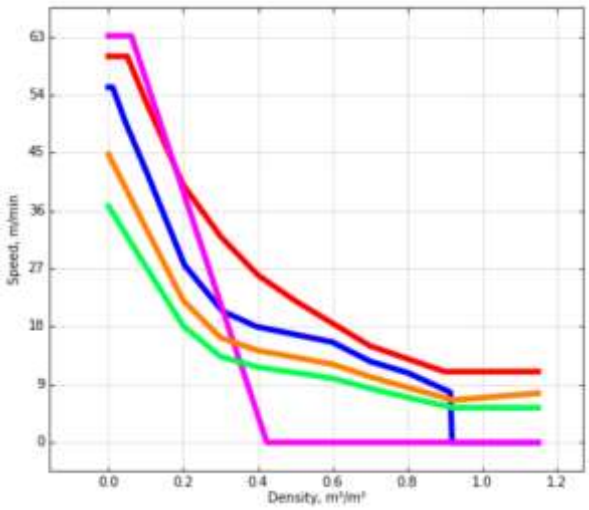



*Figure 6: fundamental diagram options*

Diagrams options:

- Fire risk assessment guidance, order No 749, Russia
- DIN 18009-2, Germany – Predtechenskii, extremal movement
- SFPE Guide, USA
- Predtechenskii, normal movement at density < 0.92, extremal movement at density > 0.92
- Predtechenskii, comfort movement at density < 0.92, extremal movement at density > 0.92

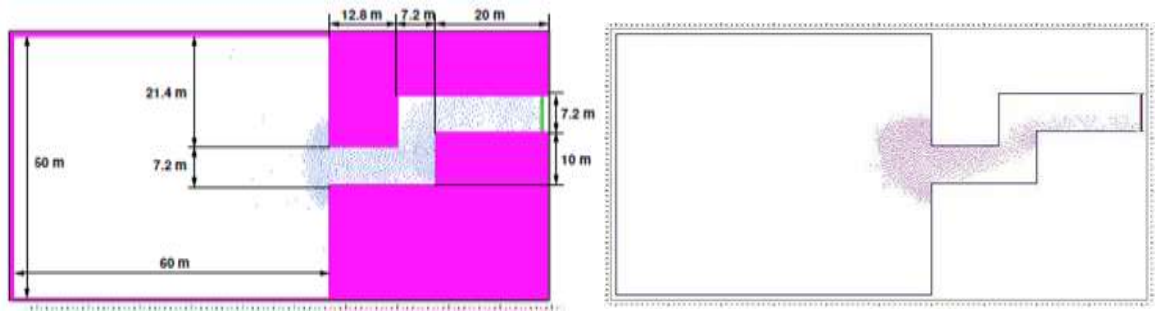
## Verification example 1

Verification example 1 - Test case FDS-EVAC, Test 6.3.3

Goal of simulation and analysis – comparison of developed model with several other models – FDS-EVAC, Simulex, Exodus.

Test case model – a room 50x60 meters, connected to exit with corridor 7.2 meter wide with two turns.

There are 1000 people in the room.



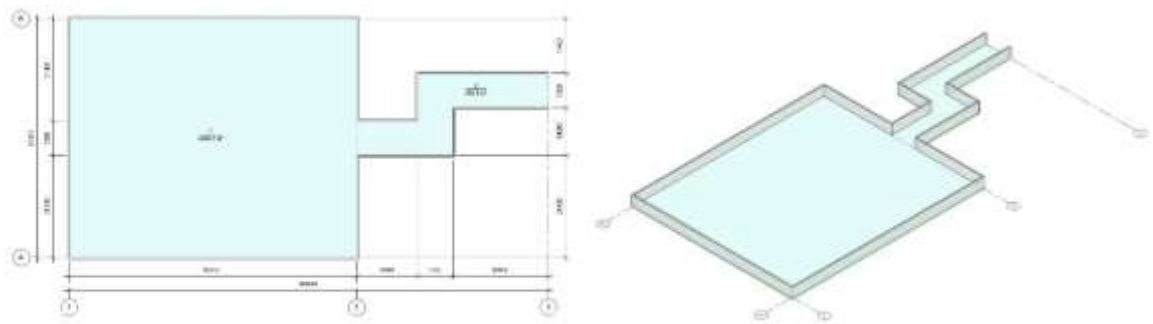


*Figure 7: example 1 test case model (top) FDS-EVAC user guide (bottom) Revit BIM model*

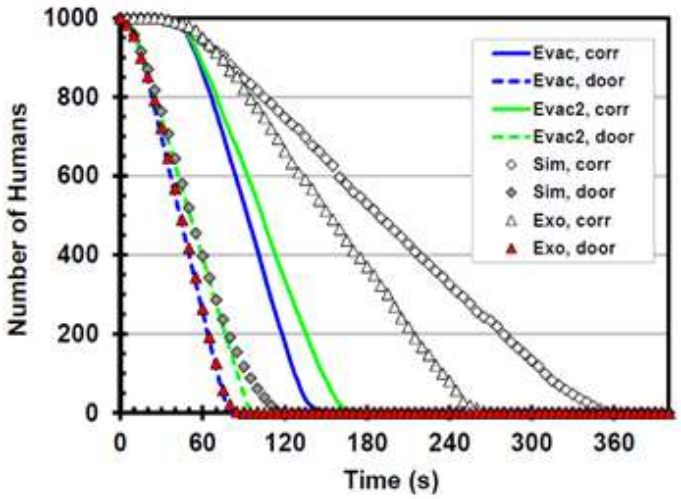



*Figure 8 reference data from FDS-EVAC user guide*

Simulation results and references are shown on the diagram at figure 9.

Simulation results, fundamental diagrams options:

-- Fire risk assessment guidance, Russia - DIN 18009-2, Germany

- SFPE Guide, USA - Predtechenskii, normal movement

- Predtechenskii, comfort movement

Reference data

FDS-EVAC option 1 FDS-EVAC option 2 Exodus

Simulex

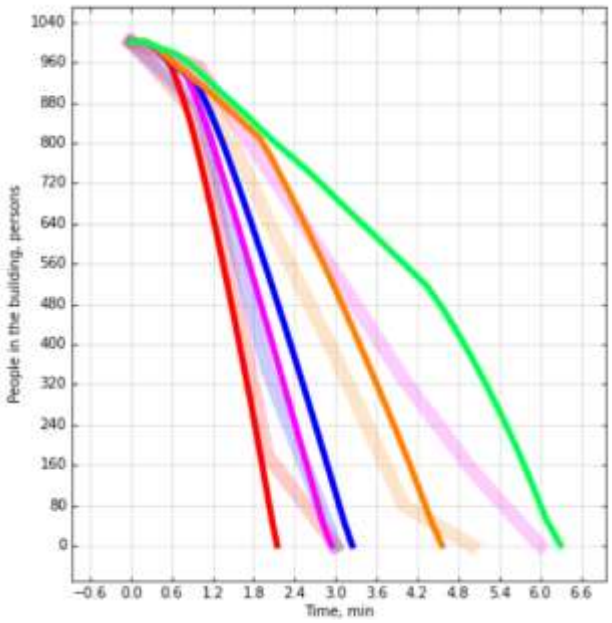



*Figure 9 : example 1 simulation and reference data*

The diagram demonstrates that developed macroscopic model simulations with variation of fundamental diagram options correlates with results of other models

## Verification example 2

Verification example 2 - WTC1 evacuation at 11 september 2001

Goal – simulation results comparison with observed data – evacuation of 7650 survivors in WTC1, located at 3 to 92 floor

Test case model –WTC1 building model, according to NCSTAR 1-7. Some simplification was made – all stairs go down to floor 1 ( ground floor), there is one wide exit on the floor 1. The simplifications aim is to neglect way finding of nearest exit in simulation results.

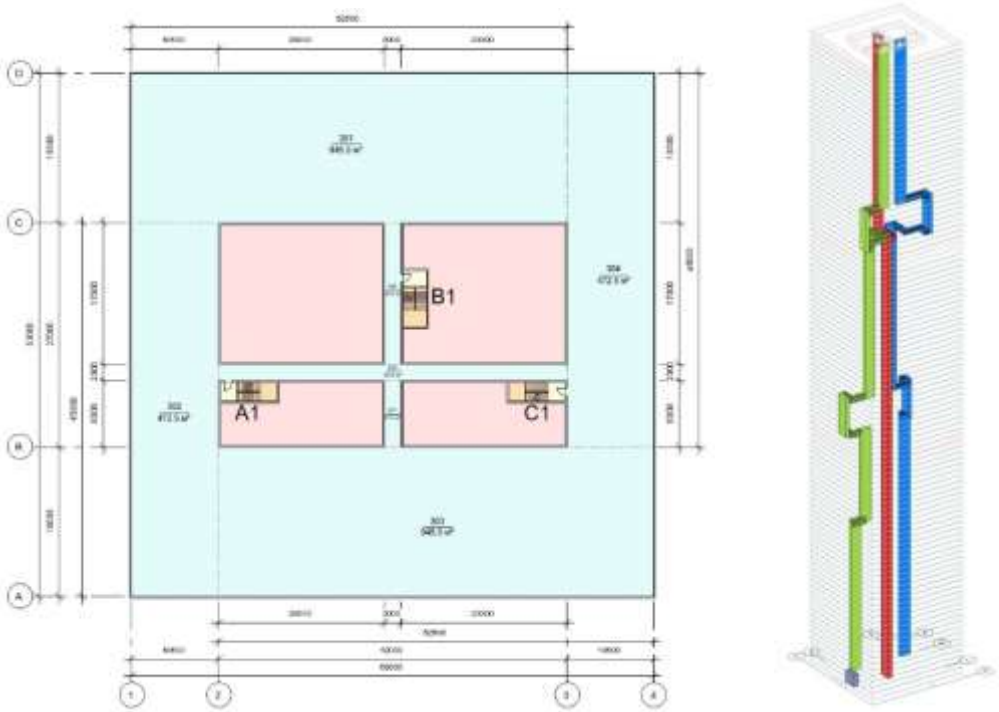


*Figure 10: : example 2 Revit BIM model (left) typical floor plan (right) staircases 3D view*

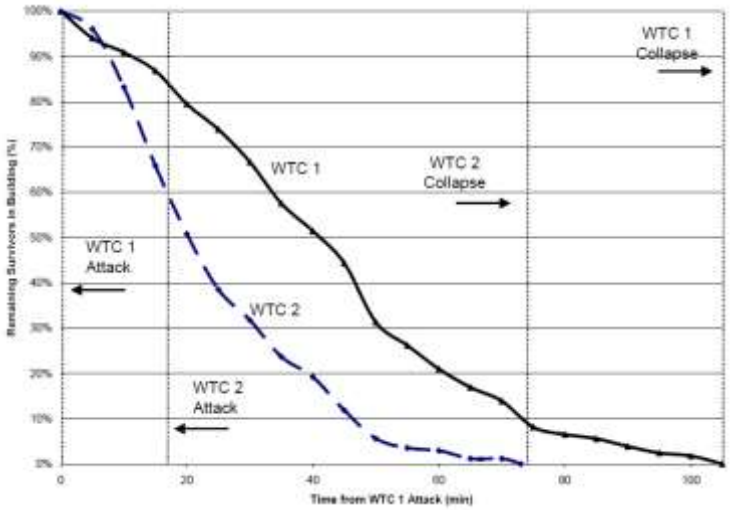



*Figure 11: WTC1 and WTC2 reported evacuation time , NCSTAR 1-7 figure 10-1*

Simulation results and reference are shown on the diagram at figure 12.

Simulation results for fundamental diagrams options:

-- Fire risk assessment guidance, Russia - DIN 18009-2, Germany
- SFPE Guide, USA - Predtechenskii, normal movement
- Predtechenskii, comfort movement

Reference data - NCSTAR 1-7 figure 10-1

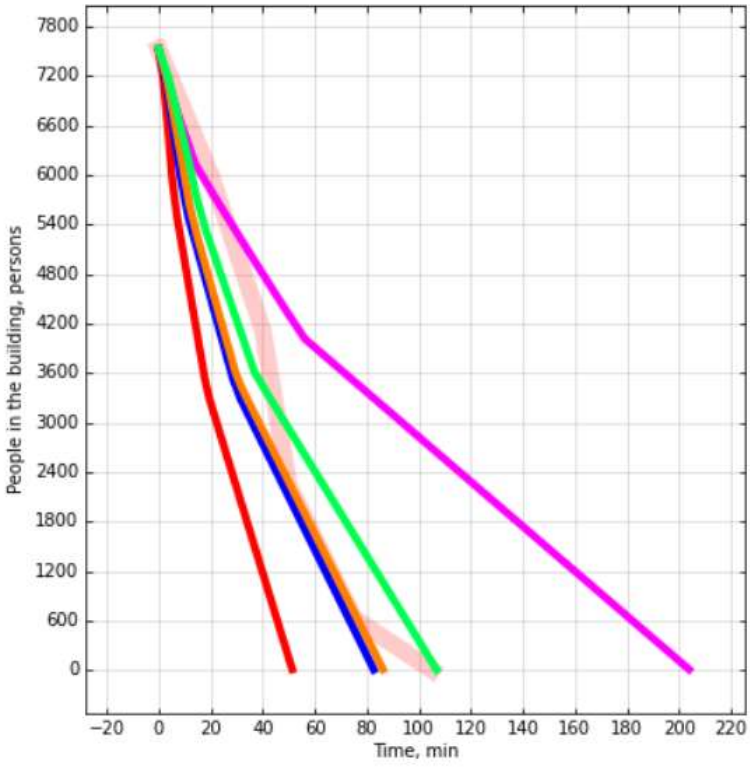



*Figure 12: example 2 simulation and reference data*

The diagram demonstrates correlation of simulation results with observed data.

## Simulation data size

To compare simulation data size of macroscopic and microscopic pedestrian dynamics models a set of simulations was performed. The developed macroscopic model, and FDS-EVAC and Pathfinder microscopic models were used. In each simulations there were three scenarios (options) of different occupancy distribution in modeled buildings, ad two options of number of pedestrians 1000 and 2000 persons.

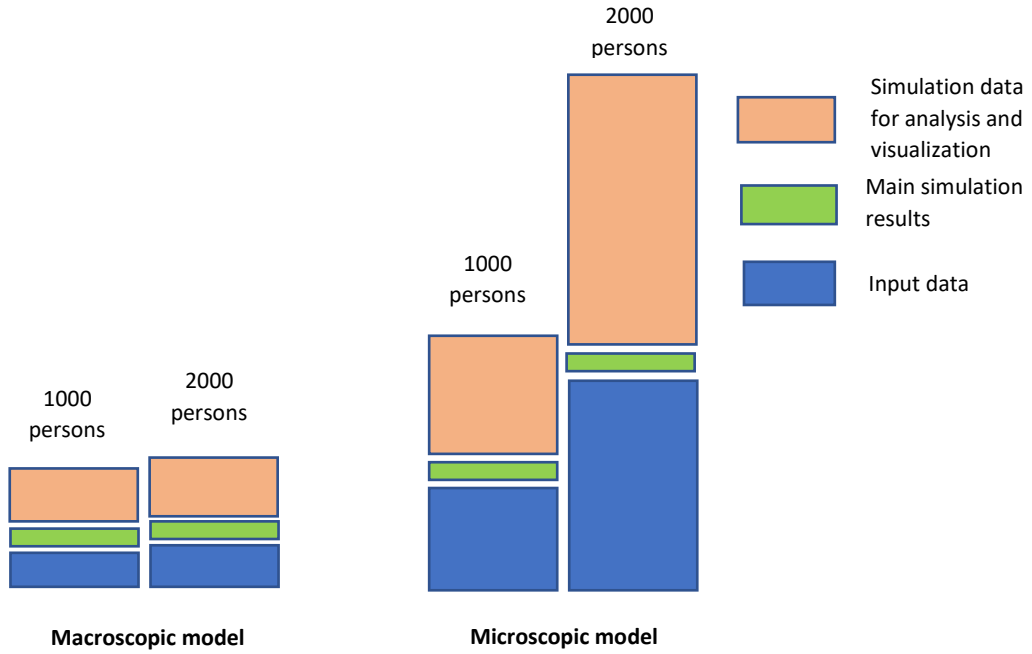



*Figure 13: Simulation data size diagram*

The size of main simulation results data (total evacuation time, evacuation time from specified rooms, speed and density in specified regions, etc) is relatively the same, but input data and overall simulation results size is much more bigger in microscopic models. The modelling and simulation data size in microscopic models greatly depends on the scenarios number and pedestrians quantity.

## CONCLUSIONS

Software tools for FSE simulations in BIM environment are developed and now are available for beta testing – Revit add-in and linked FSE modelling processors and reporters.

Macroscopic evacuation model for pedestrian movement at fire evacuation and normal circulation, suitable for BIM-FSE integration, is developed and is available for betta testing and verification

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