The use of PyroSim graphical user interface for FDS simulation of a cinema fire

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***Abstract*—**In this paper, creation of geometry of a small cinema for the purposes of fire simulation in the PyroSim system is described. PyroSim is a graphical user interface for the computational fluid dynamics fire simulator, Fire Dynamics Simulator (FDS). It allows creating efficiently the input geometry of complicated structures for the FDS simulation of various fire scenarios. The creation of the cinema hall with several complex construction elements allows us to demonstrate the usefulness of PyroSim for computer simulation of fires in buildings with complex geometry. A typical fire scenario in such cinema is described. The course of fire and smoke development are simulated with the emphasis on spectators' safety.

***Keywords*—**computer simulation, cinema fire, FDS, graphical user interface, PyroSim, input geometry

I. INTRODUCTION

Computer simulation of fires has become an important tool for analysis and improvement of fire safety especially in the countries, where high-level fire research is conducted. Several advanced simulation systems capable to simulate and visualize fire in complex environments such as for instance Fluent, SMARTFIRE, CFX, FDS, have been developed.

Fire Dynamics Simulator (FDS, version 5.5.3) [1, 2, 3, 4] is a Computational Fluid Dynamics simulation system developed by NIST (National Institute of Standards and Technology) in the USA. It includes numerous physical and chemical processes associated with fire and smoke spread. It covers modelling of low-speed thermal flows and combustion of pyrolysis products, heat radiation and convective transfer of heat between gases and solid surfaces, pyrolysis, flames and smoke spread, sprinklers activation, heat and smoke detectors, and suppression. The system numerically solves a form of Navier-Stokes equations for low-speed, fire induced flows with emphasis on transport of smoke and heat from fire. The course of fire, smoke development, and various quantities related to fire can be visualised by the 3D visualisations system, Smokeview [5]. All objects in the space in which the fire is to be simulated must respect the space division onto 3D rectilinear computational meshes composed of cells. Creating the input geometry for FDS simulations is a complicated, labourious and time-consuming process especially for complex models with many complicated components.

Nowadays, several advanced graphical user interfaces (GUI) and auxiliary conversion tools are available for FDS, such as PyroSim, BlenderFDS, 3dsolid2fds, acad2fds, etc. We tested the PyroSim GUI (version PyroSim 2011) [6] in order to facilitate preparation of inputs for FDS simulations in complex environments.

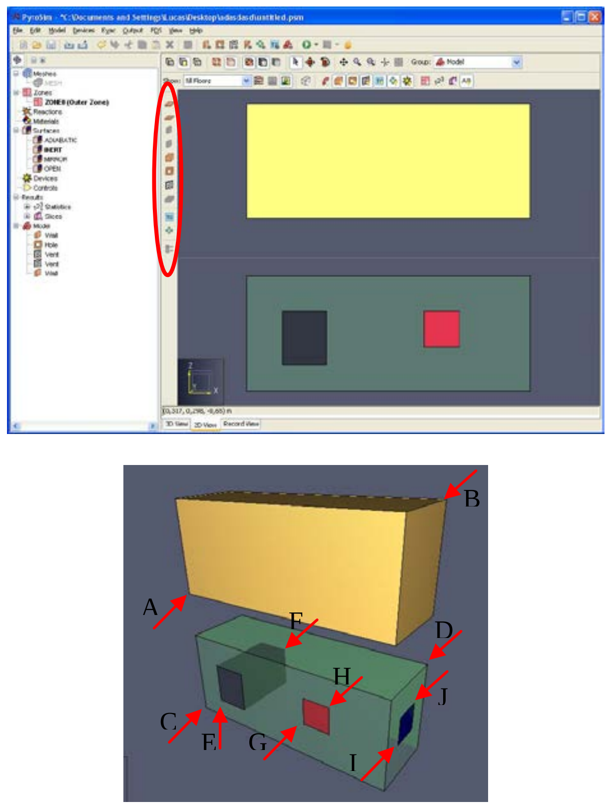

Figure 1. Examples of basic elements in PyroSim representing the input FDS geometry (2 obstructions, 1 hole and 2 vents): 2D View with highlighted PyroSim tools (top) and cut-out of 3D View with highlighted points representing the corresponding elements (bottom)

PyroSim was developed by Thunderhead Engineering Consultants, Inc. (USA). The main functions of PyroSim cover an interactive creation of complex models (the use of ground plans, creation of multiple repetitious objects, curved walls, stairways, etc.), import of existing FDS4 and FDS5 models, PyroSim models, and 2D/3D AutoCAD DXF and STL models (see also [7]). PyroSim enables importing a ground plan, saving it as a background image and displaying it in its 2D or

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3D View modes. The background image scale can be modified to correspond to the computational mesh chosen for intended FDS simulation. This feature greatly facilitates the creation of geometry of complicated models.

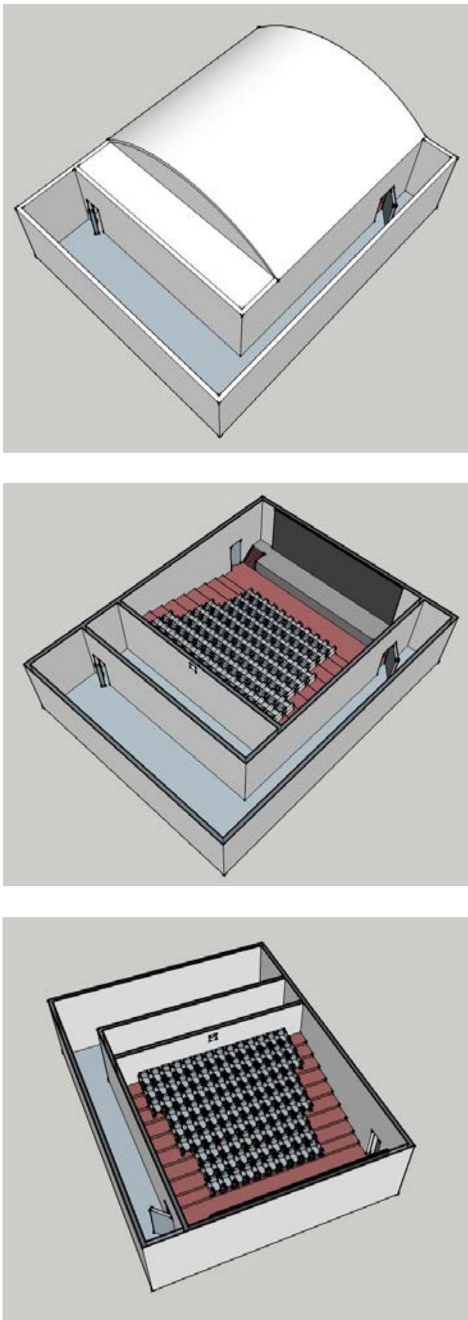

Figure 2. 3D cinema model

In the 2D View mode, there are several useful tools (highlighted in Fig. 1, top) for creating the basic elements (obstructions, holes and vents), which represent the input FDS geometry of objects appearing in buildings, and their combinations, such as the *Draw an Obstruction, Draw a Hole, Draw a Wall, Draw a Wall Hole, Draw a Block, Draw a Block Hole, Draw a Vent, Draw a Room, Draw an Init Region, Draw a Particle Cloud* and *Tool Properties*. In Fig. 1, a single obstruction (yellow) and an obstruction (green) with a hole (grey) and two vents (red and blue) are shown. Each obstruction, hole and vent is represented by a couple of points, i.e., by (A, B), (C, D), (E, F), (G, H), and (I, J) for yellow obstruction, green obstruction, hole, red vent, and blue vent, respectively (see Fig. 1, bottom). It means that obstructions and holes, and vents are 3D, and 2D objects, respectively.

Several papers related to FDS simulations of fire in structures with a critical concentration of people (fire in theatre [8, 9], supermarket [10], compartment [11, 12, 13], atrium [14], multipurpose hall [15], buildings [16, 17]) have appeared in the literature. However, only few papers have been devoted to the use of the PyroSim GUI for fire simulation in such structures (e.g., in a theatre [8], multipurpose hall [15], warehouse [18], compartment [11, 12, 13]).

In this paper, we utilize our experience with fire simulations in complex environments [19, 20, 21, 22], particularly with the use of FDS for simulation of car fires [23, 24, 25] and tunnel fires [26, 27]. We demonstrate creating the input FDS geometry of a typical small cinema by PyroSim for the purposes of the cinema fire simulation. The short version of this paper has been presented at the ECS 2012 conference [28] and some preliminary results have been published in [17, 30].

The paper has the following structure. In Section 2, a 3D model of a cinema with sloping floor and curved ceiling is described. Section 3 demonstrates in detail creating the input FDS geometry of the cinema by PyroSim. In Section 4, simulation of a typical fire scenario in the cinema is illustrated. Section 5 summarizes the main results of the paper.

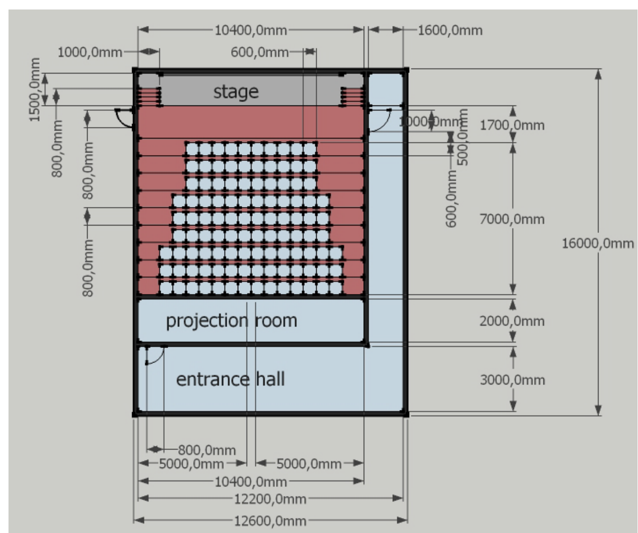

Figure 3. Cinema ground plan

II. Cinema description

In order to demonstrate the use of PyroSim for FDS simulation of cinema fires, we used Google SketchUp to make a 3D model of a typical small cinema containing several complex construction elements (see Fig. 2). The cinema consists of the entrance hall (12.2 m x 3.0 m x 4.8 m and 1.6 m x 12.6 m x 4.8 m), projection room (10.4 m x 2.0 m x 4.8 m) and cinema hall (10.4 m x 10.2 m x 4.8 m). The cinema hall contains a stage with 2 stairways on its sides, curved ceiling, and seating space for spectators with 108 chairs organized into 9 chair rows standing on 20 cm high stairs (the 1^{st}, 2^{nd}, and 3^{rd} triple of chair rows has 10, 12, and 14 chairs, respectively). The rows and chairs are numbered from the podium frontways and from the left, respectively. The ground plan of the cinema is shown in Fig. 3. Each chair in the model (see Fig. 4) consists of 4 upholstery cuboids representing the seat (0.4 m x 0.6 m x 0.1 m), seat back (0.4 m x 0.1 m x 0.4 m) and 2 hand rests (0.1 m x 0.6 m x 0.5 m).

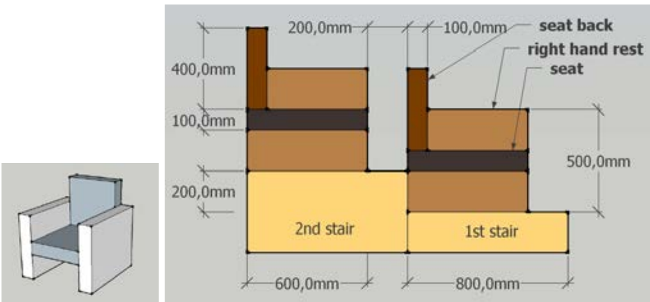

Figure 4. Upholstered chair schemes

III. Cinema input geometry creation

In this section, we show how to use the imported cinema ground plan to create particular construction elements of the cinema.

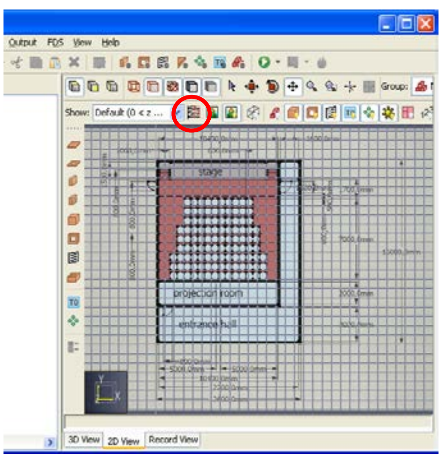

Figure 5. Ground plan import

A. Ground plan import

To import the file containing the cinema ground plan into PyroSim, we clicked on the *Define Floor Locations* tool in the 3D (or 2D) View mode (see the 1^{st} icon at the 3^{rd} toolbar highlighted in Fig. 5), opened the *Manager Floors* tool, set the model name, floor height (0.0 m) and ceiling height (3.0 m), and used the image file browser. After the image import, we configured the background image by setting the *Anchor Point* (the coordinate system centre) and a selected known distance between two points lying in the ground plan (using the *Choose Point A* and *Choose Point B* tools). The default value of the PyroSim Sketch Grid density was 1 m. Therefore, we set the value of Sketch Grid density to 0.1 m using the *Sketch Set Grid Spacing* tool in order to achieve the correspondence between the Sketch Grid and computational mesh chosen for intended FDS simulation (see Fig. 5). This procedure facilitates the objects drawing in the 2D View mode.

B. Walls creation

Walls were created gradually using the ground plan. We clicked on the *Draw a Room* and *Tool Properties* tools in 2D View mode and opened *New Room Properties*. We set the height of room (4.8 m), wall thickness (0.2 m) and suitable values of wall colour and transparency. Then, we clicked on the left-most lower corner in the ground plan, dragged the mouse into the opposite corner (right-most upper one), and made a mouse click. These walls are highlighted in yellow in Fig. 6 (top). Similarly, we created all other walls in the cinema and continuously deleted unnecessary ones marking them and making the *Delete* key click. The created walls are highlighted in yellow in Fig. 6 (bottom). Since each wall is represented by a 3D obstruction in FDS, this procedure allowed us to avoid the manually complicated and laborious calculation of the corresponding couple of obstructions vertices coordinates.

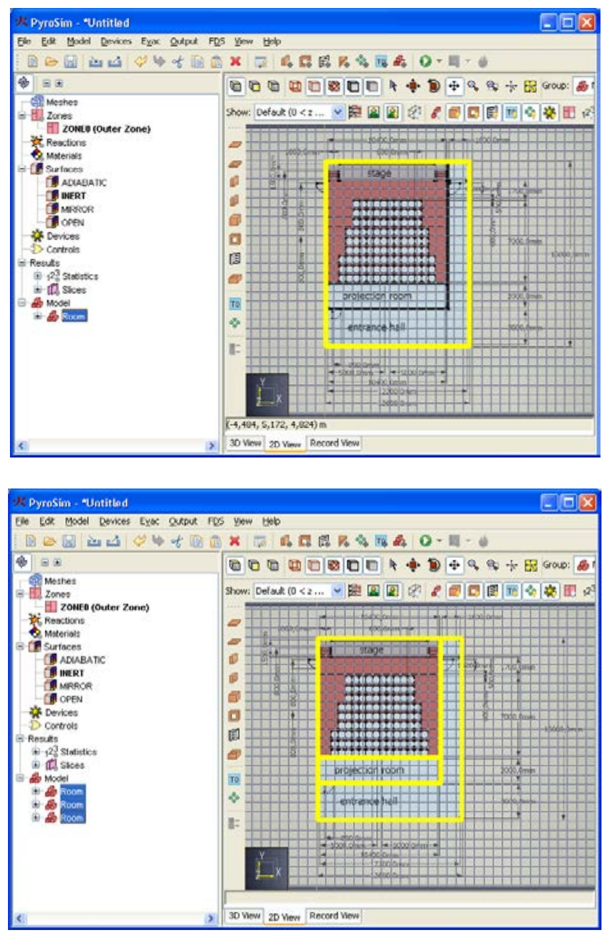

Figure 6. Walls creation

C. Chair creation

Each chair in the cinema was represented by 4 obstructions corresponding to the seat, seat back and hand rests. We clicked on the *New Obstruction* tool in 3D View mode and entered the corresponding couples of the opposite vertices representing these obstructions, i.e., the couples (2.4, 12.0, 0.2) and (2.5, 12.6, 0.7), (2.9, 12.0, 0.2) and (3.0, 12.6, 0.7), (2.5, 12.0, 0.4) and (2.9, 12.6, 0.5), and (2.5, 12.0, 0.5) and (2.9, 12.1, 0.9), for the left hand rest, right hand rest, seat, and seat back, respectively (Fig. 7).

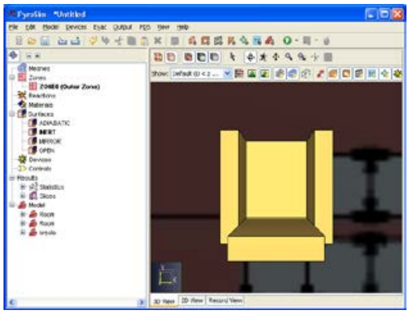

Figure 7 Chair creation

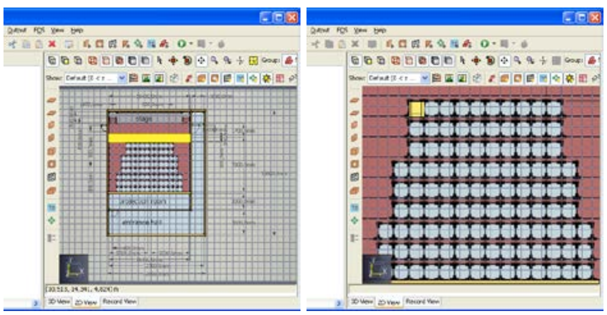

Figure 8. The 1st stair creation and placement of the 1st chair according to the ground plan

D. Cinema hall sloping floor and spectator seating space creation

Sloping floor in the cinema hall was created as a staircase consisting of nine 20 cm high stairs (represented by obstructions) on which the chairs rows were placed. First, we created the first stair with chairs. We clicked on the *Draw an Obstruction* tool, set the stair height value, *Max Z*, to 0.2 m in the *Tool Properties*, clicked on one of the first stair corners and dragged the mouse diagonally onto the opposite stair corner making a mouse click (see Fig. 8, left). Then, right-clicking on the stair, we made it invisible using the *Hide Objects* tool. Next, we used the ground plan for simplifying the placement of individual chairs onto their correct position. We clicked on the *Translate Objects* tool and moved the chair created in advance onto the first chair position (see Fig. 8, right).

Then, we right-clicked, selected the *Copy/Move* tool and set the values of the *Number of Copies* and distance in meters in the *X*-axis direction (*Offset X*, see Fig. 9, top). Next, we made the stair visible using the *Show Objects* tool. We selected the first stair and the chairs placed on it (Fig. 9, bottom) and copied this object similarly as in the case of the first chairs row creation by setting the necessary values of the *Number of Copies*, *Offset Y*, and *Offset Z* to 8, -0.8 m, and 0.2 m, respectively (see Fig. 10, top). The sloping floor consisting of nine stairs with 10 chairs is highlighted in yellow in Fig. 10 (middle). Then, we added the missing chairs according to the ground plan. By this procedure, we created the seating space for spectators consisting of 108 chairs (see Fig. 10, bottom) placed on the stairway which is used by spectators to access their seats. The total number of used obstructions is 441. We benefited by the use of the PyroSim tool for handling with multiple repetitious objects and by the ground plan imported as a background image which made placing objects onto their proper place easier.

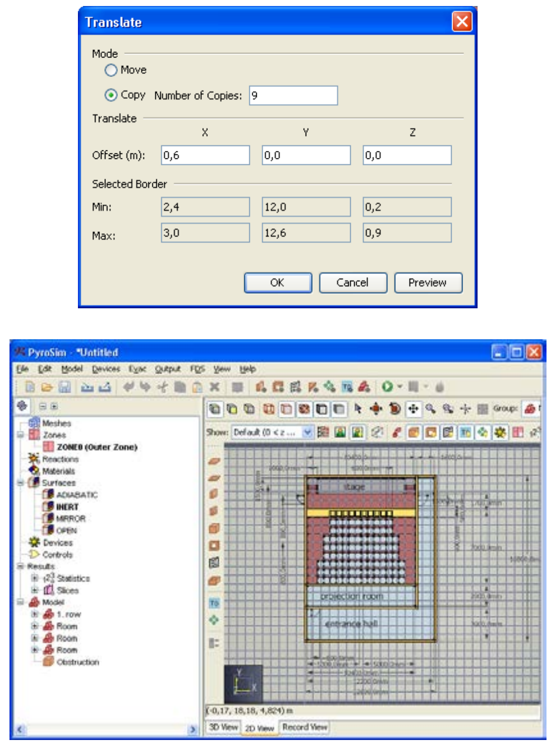

Figure 9. Dialog window for the 1st stair chairs creation and the resulting object highlighted

E. Stage creation

The stage in the cinema hall is represented as a 0.8 m high stair (obstruction) with two small stairways (groups of obstructions) at its sides. In 2D View mode, we clicked on the *Draw an Obstruction* tool, set the value of the stair height to 0.8 m using the *Tool Properties* and created the stage similarly as when creating stairs. The stairway on the left stage side was made by clicking on the *Draw a Hole* tool and creating a hole at the place of the left small stairway according to the ground plan. Then, we created the first stair clicking on the *Draw an Obstruction* tool, setting the *Max Z* height value to 0.1 m and unchecking the *Permit holes* check box in the *Tool Properties*. The first stairway was created using the *Copy/Move* tool by copying the 1st stair seven times. Next, we copied the created hole and stairway as a single object (using the *Copy/Move* tool with the 9.4 m *Offset X* value). Thus, we created the second stairway in the stage. The complete stage with its stairways is highlighted in yellow in Fig. 11. It is represented by 17 obstructions and 2 holes.

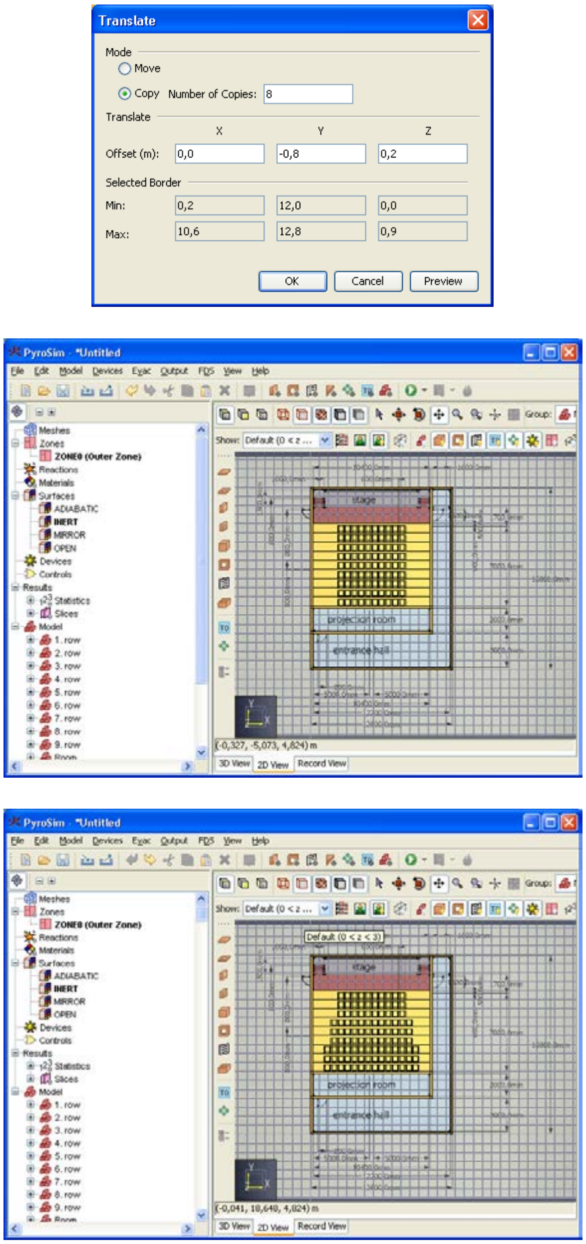

Figure 10. Seating space creation

F. Doors creation

Doors in the cinema were closed. We represented them by vents (see Fig. 12). In the *Tool Properties* tool in 2D mode, we set the value of the door height to 2.0 m and clicked on the *Draw a Vent* tool. Then, we created a *Vent* by mouse at the place of the projection room door according to the ground plan by clicking on one of the door corners and dragging into the opposite corner. Similarly, we created the entrance door and emergency exit in the cinema hall. In this case, we used the interactive PyroSim tool which made the vents creation faster and more simple.

G. Curved ceiling creation

The curved ceiling in the cinema hall was the most complex construction element in the model. It can be represented by a great number of obstructions which form its flat horizontal and curved side parts. Total number of obstructions depends significantly on chosen computational mesh density. In order to create the FDS representation of the ceiling, we made a C++ program [29]. It calculates the corresponding couples of corners related to the individual obstructions forming the ceiling and writes them in proper FDS syntax into an external text file. Then, we copied this block of obstructions into the corresponding input FDS file and imported the file into PyroSim. Finally, we modified the transparency of some walls to improve visibility of the created ceiling (see Fig. 13). Total number of obstructions was 65. The program uses the input ceiling proportions, curvature and given computational mesh density, and automatizes the calculation of coordinates of the obstructions which form the ceiling. It utilizes the knowledge about the syntax of FDS representation of solids.

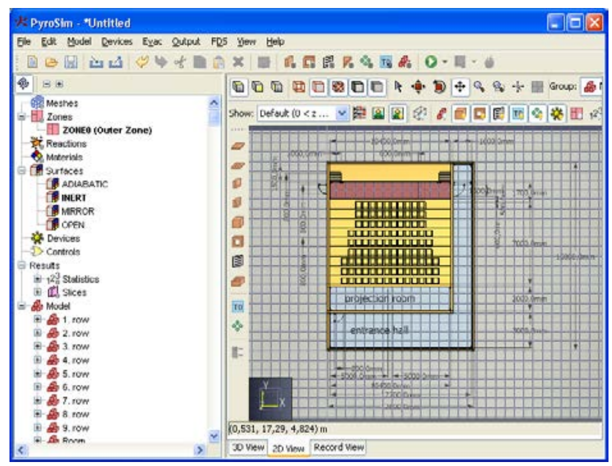

Figure 11. Stage creation

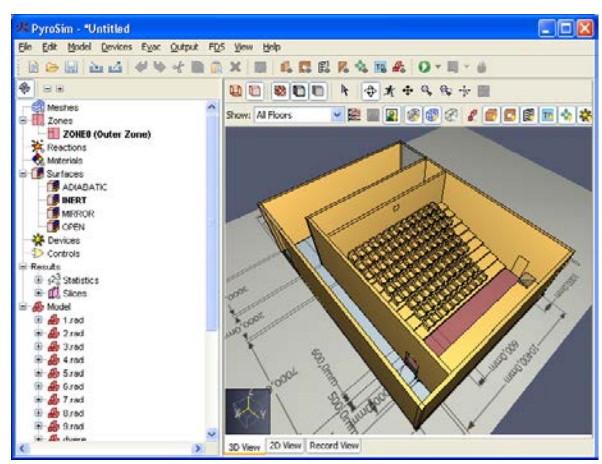

Figure 12. Doors creation

IV. Cinema hall fire simulation

In this part, the potential of FDS for capturing the main specific features of the fire behaviour in the cinema is illustrated.

We assume a fire ignited under the 7th chair in the 5th row in the cinema hall. The doors are closed. The initial fire source is represented by a 0.2 m x 0.2 m burning surface with

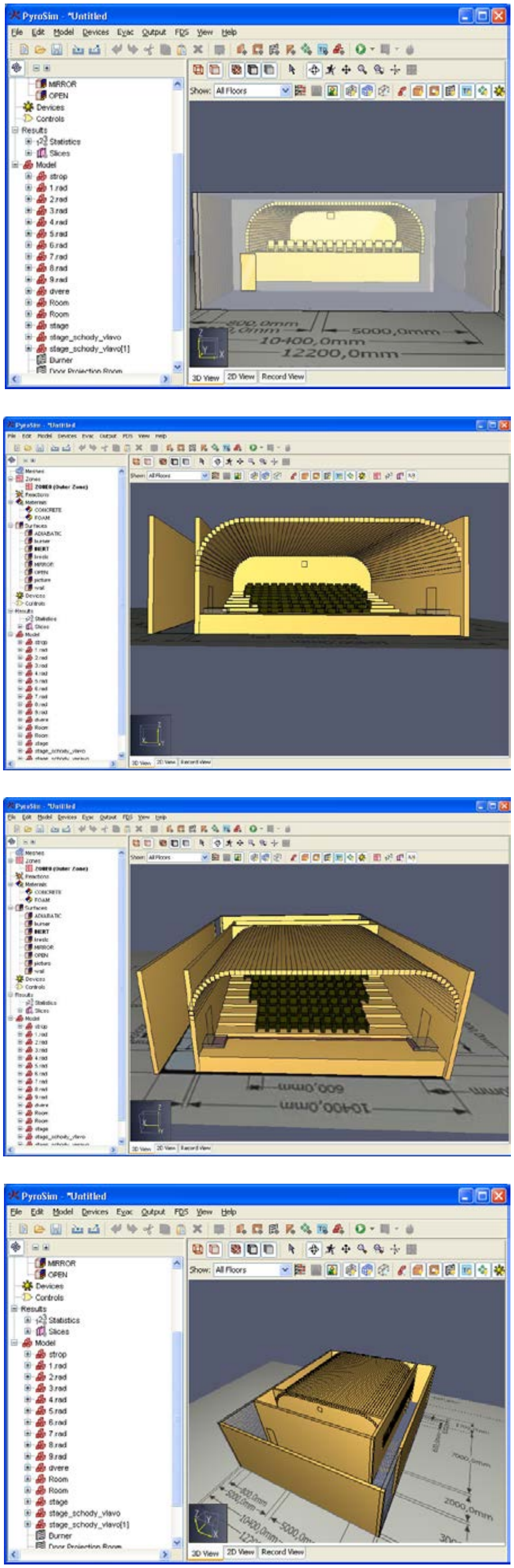

Figure 13. Ceiling creation

the 800 kW/m^2 HRRPUA (heat release rate per unit area) during 3 s of fire.

We use three types of materials in the simulation: concrete, upholstery, and inert material for walls, chairs, and other surfaces, respectively. Material parameters for the upholstery material which dominantly contributes to the fire intensity and toxicity of smoke released during the fire were determined by laboratory measurements and validated by fire tests and FDS simulations [31].

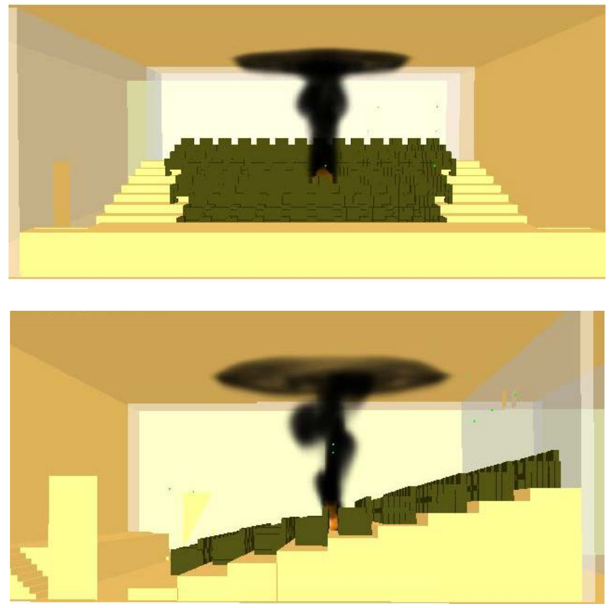

Figure 14. Fire and smoke spread at the 6th s

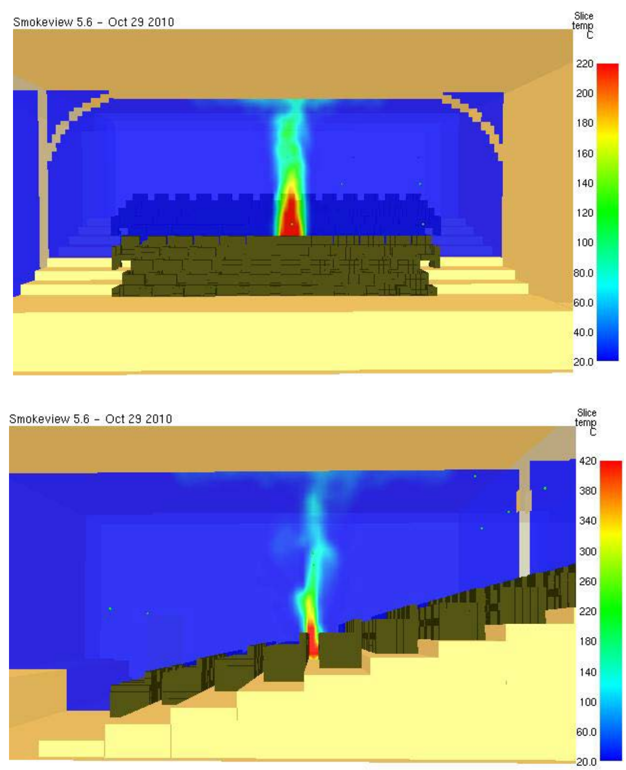

Figure 15. Temperature distribution at the 6th s

The computational space was represented by a single computational mesh of 10 cm density. It divided the space into 126, 160 and 48 cells in the direction of *x*-, *y*- and *z*- axes, respectively. Total cells number was 976 680. Total computational time of 1-minute fire simulation on Core i7 990-X 3.46GHz, 24 GB RAM was about 2.94 hours.

The course of fire was as follows. In the beginning, a thin column of hot gases begun to spread up to the ceiling. After its hit into the ceiling, it spread under the ceiling in all directions. The dominant fire spread was in the *y*-axis direction.

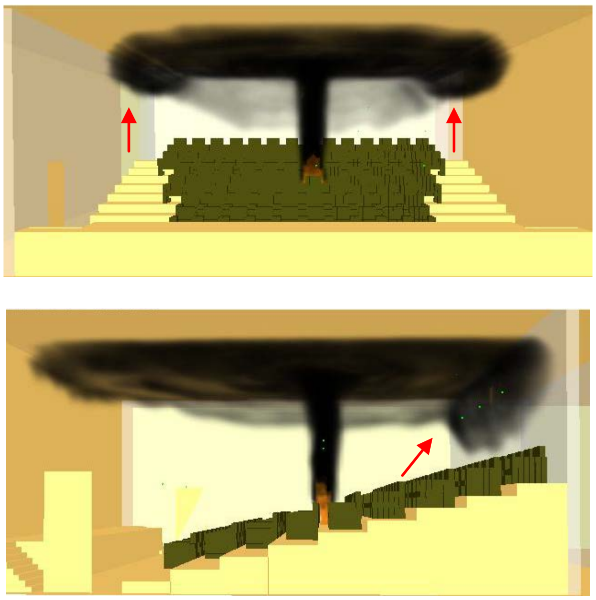

Figure 16. Fire and smoke spread at the 12^{th} s

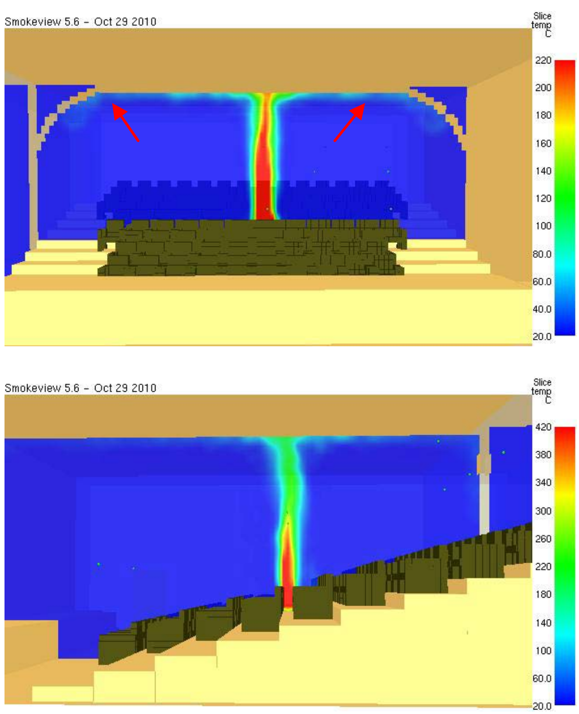

Figure 17. Temperature distribution at the 12^{th}

In the 4^{th} second of fire, smoke hit the curved parts of the ceiling. In Fig. 14, the forward and side views of the simulation of fire and smoke spread at the 6^{th} second are shown. Fig. 15 describes the temperature distribution at that time. The figures shown that the toxic gas clouds begun to origin at the back part of the cinema hall and under the curved parts of the ceiling. However, at that time the toxic smoke development did not start to jeopardise spectators, yet. Note that the orange colour in pictures represents the fire with 200 kW/m^3 intensity.

After the 12^{th} second, the toxic clouds originated at the back part of the cinema hall and under the curved parts of the ceiling started to endanger spectators (see Figs. 16-17).

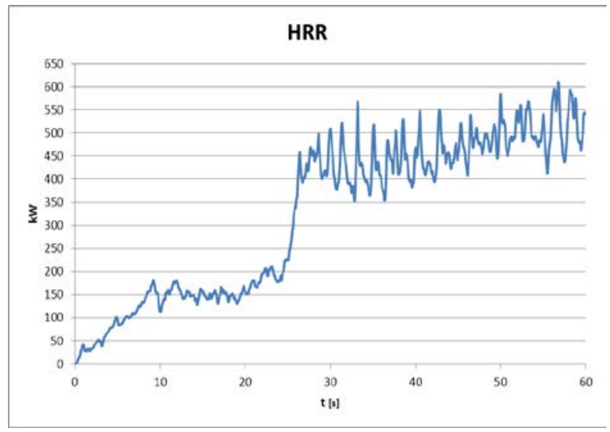

Figure 18. Heat release rate (HRR) curve of the fire

It is seen in the Heat release rate (HRR) curve, that the fire intensity between the 10^{th} and 25^{th} second of fire stagnated (see Fig. 18). Since 25^{th} second, a significant increase of HRR can be observed which corresponds to the increase of burning surface. At that time, the fire spread from the bottom part of the seat to the top part of the seat and the front part of the seat back.

Since the 40^{th} second of fire, the toxic gas layer thickened and started to endanger spectators sitting in the highest chair rows in the cinema hall (see Figs. 19-20).

V. Conclusions

In this paper, the use of the PyroSim GUI for efficient creation of inputs for FDS simulation of a cinema fire is demonstrated. A typical small cinema with sloping floor and curved ceiling is described. It is shown, how the cinema ground plan import facilitates interactive creating the cinema input FDS geometry. In FDS, objects placed in simulated space are represented by a short set of basic elements (obstructions, vents, holes) which must conform to given computational mesh. Since the geometry representation of the cinema comprises of a big amount of such elements, creating its input FDS geometry would be laborious and time consuming.

It is shown how user benefits by PyroSim tools handling with multiple repetitious objects and easier placement of objects onto their proper position. It allows to avoid inevitable manually complicated calculation of vertices coordinates

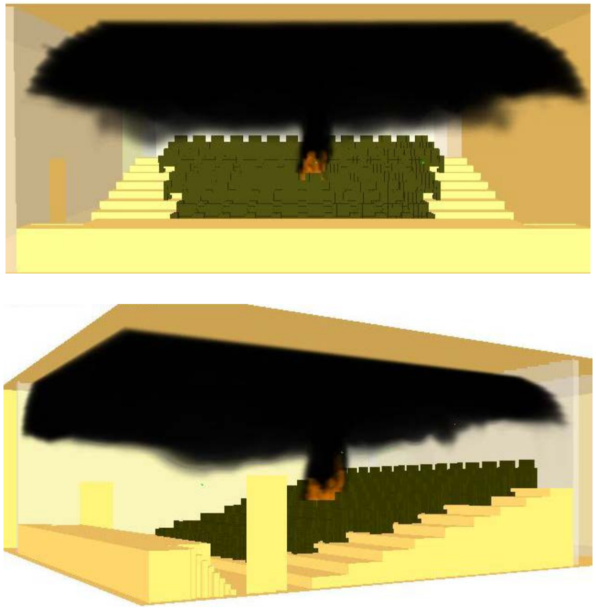

Figure 19. Fire and smoke spread at the 40th s

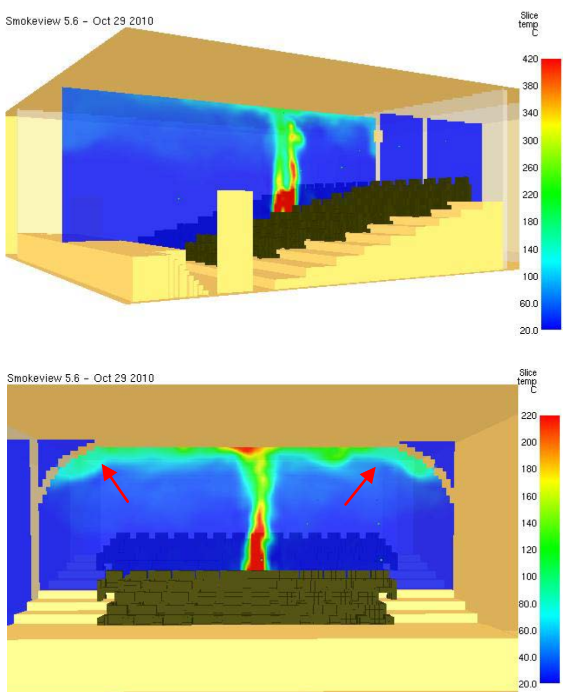

Figure 20. Temperature distribution at the 40th s

which define the obstructions, vents and holes representing the cinema. The simulation results of a cinema fire scenario indicates that FDS has a great potential for capturing specific tendencies of fire and smoke spread in structure with complex geometry. The simulation confirmed that the most dangerous places in the cinema hall are the seats in the highest chair rows and both sides of the cinema hall under the curved ceiling. This paper is an extended version of the paper presented at the ECS 2012 conference. Some preliminary results have already been published in [17, 30].

For simulation of fire in bigger structures with complex geometry, it will be necessary to realise the calculations in parallel manner on multi-core computers, clusters of computers, or grids using parallel versions of FDS. Other flammable materials could be also added in the simulation studying the impact of multi-layer materials and/or composite materials on the simulation. Aspects of safe evacuation from burning structures will be also a subject of our research in future.

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