Virtual Reality for Fire Safety Engineering

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ABSTRACT

Fire Safety Engineering allows the fire designer to carry out analysis for the study of fire simulation, through the use of CFD and egress modeling, through the use of numerical models. This paper aims to develop a method able to export the fire and egress simulation in virtual reality and consequently visualize the results within a VR system. In this respect, a result is a tool that is available to several figures and capable of satisfying different needs.

One of the objectives set by the authors is to improve the designer's interpretation of fire evolution and its effects. In this context, the aim is to be able to design an effective escape system in terms of the position of signage and fire-fighting equipment and to achieve improved wayfinding for the studied environment.

Just as complex as the verification and design phases are the management phases during an emergency. The method makes it possible to respond to the requirements that emerge after the design phase. In this context, the proposed tool provides support during the training of emergency staff and for the regular users of the analysed environment, i.e. the end-users of the spaces.

In particular, the development of an application is proposed that allows the real-time monitoring of fire effects, occupants, signage systems, and fire scenarios. The method represents an aid to research tools related to the world of Fire Safety Engineering and virtual reality, as it can fully immerse the user in the environment and evaluate its performance from the point of view of fire prevention.

Keywords: Fire Safety Engineering, Virtual reality, Serious games, Participatory process

INTRODUCTION

The evolution of technologies in the field of engineering and design has contributed to the realisation of buildings characterised by complex geometries, as a consequence, the compliance with the technical rules on fire prevention is more and more complicated. The development in the research sector has involved many innovations in fire prevention methods and approaches.
We are witnessing a gradual transition from prescriptive methods to performance-based approaches. The designer now has a key role to manage the decision-making phase of fire safety measures; with Fire Safety Engineering tools, the designer is able to demonstrate the efficiency of the proposed solutions.
The aim of the authors is to explore the potential of current tools such as virtual reality applied to the fire engineering sector. The aim of the authors is to explore the potential of current tools such as virtual reality applied to the fire engineering sector.
Some applications are shown that are able to improve the consciousness and knowledge of the emergency dynamics in the so-called fire scenario.

FIRE PREVENTION AND FIRE SAFETY ENGINEERING

Fire safety engineering is a subject whose characteristics and definitions were first presented in the technical report ISO/TR 13387 of 1999. There are various synonyms for this terminology, some of which are: engineering approach, fire safety engineering, performance based approach. It can be defined as the subject that uses scientific methods to help the designer to choose the most appropriate safety measures to protect people, objects and the environment from the effects of fire. The technical report ISO/TR13387 provides the following statement to describe the performance methodology:
"*The application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, of the effects of fire, and the reaction and behaviour of people, in order to: save life, protect property and preserve the environment and*
heritage; quantify the hazards and risk of fire and its effects; evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire".

Nowadays, most countries have regulations that include and guide an approach to fire prevention based on fire safety engineering. FSE approaches consider the totality of fire prevention and protection measures and provide a better and more affordable solution than traditional fire protection methods.

In some cases, this approach is the only possible means of achieving a successful level of fire protection. The international FSE regulations, consider the interaction between fire, buildings and occupants, and require the study of fire scenarios.
ISO/TR 13387, provides a flexible structure and method to create a fire protection design that can be easily evaluated by authorities. Combined with ISO/TR 13387, British Standards 7974 provide a framework for an engineering approach to the implementation of fire safety in buildings. These standards contain advice and guidance on the application of scientific and engineering principles for life safety. The BS provides a framework for developing a rational methodology for the design of buildings.
This standard applies to the design of new buildings and the assessment of existing buildings.

During the fire design process, great care is required, since, at this phase, it is essential to establish all the boundary conditions and possible scenarios that may in some way interact and influence the evolution of fire dynamics and escape of people. In this context, it is necessary to examine aspects such as the egress system and how it interacts with people.
The designed system should be able to provide the right information to allow occupants to make the best choice and reach a safe place.

A more accurate design, "dressed up" according to the specific needs of the activity and the characteristics of the building, requires the concrete possibility, during the design phase, of being able to predict, quantify and evaluate a series of elements describing the fire scenario.
A prescriptive approach, which was common until a few years ago, doesn't investigate and doesn't require the in-depth study of a series of elements, which the fire safety engineering approach requires instead. An example is the alarm system, whose objective is to communicate an emergency to the occupants.
The same performance required of the system can be guaranteed and developed by different methods and tools.

Fire safety engineering in this case requires to know the detection and warning times. The above-mentioned times play a crucial role in assessing the time required for the occupants to escape and the time available for evacuation.

Escape and pre-evacuation times

The philosophy of performance-based design is that a project is focused on 'performance'. This approach needs to ensure the life safety, which has resulted in the need for designers to have egress simulation models available. Performance-based design (PBD) is based on the concept that any fire-fighting measure can be used in the design as long as it is adequate to allow an acceptable level of safety. Fire Safety Engineering is based on these principles and its main purpose is to guarantee that the occupant can safely evacuate the building in the required time. These times are calculated by comparing the ASET and RSET parameters.
ASET represents the time during which the environmental conditions persist and do not compromise the evacuation of the occupants. The calculation of ASET can be carried out according to different methods, including mathematical approaches and calculations by using computational fluid dynamics analysis using FDS calculation engines, as they relate to the dynamics of fire development and its products. It depends on the interactions between occupants, fire and environment. Similarly, several methods can be used to determine RSET, each with a different level of complexity. RSET represents the time between the start of the fire and the time when all occupants have safely evacuated the building. The time required to allow the safe evacuation of the building is formed by the sum of several factors, each of which is associated with a specific situation during the evacuation phases.

The technical report ISO/TR 16738:2009 defines it as follows:
$RSET = t_{det} + t_a + t_{pre} + t_{tra}$

where:
t_{det}: detection time, time needed for the detection system to notice the fire.
t_a: general alarm time, the time that elapses between the detection of the fire and the diffusion of information to the occupants.
t_{pre}: pre-movement time, the time required for the occupants to carry out a set of activities preliminary to movement to the safe place.
t_{tra}: movement time, the time required by occupants to reach the safe area, calculated from the end of pre-movement activities.

The RSET value is influenced by different factors, such as the extrinsic and intrinsic characteristics of the occupants, their cognitive, sensory and motor abilities, the fire detection and alarm methods, the planned escape design procedures. For this reason it is necessary for the fire designer to develop the appropriate design scenario that best fits the case under study.

FIRE PREVENTION AND FIRE SAFETY ENGINEERING

Fire safety engineering also introduces some attention to elements that are often overlooked or not even considered within a design. In addition to aspects entirely linked to the best known fire-fighting measures (compartmentalisation, fire resistance, length of escape routes, etc.), there are factors (often intrinsic to each individual involved) that can make the system studied less efficient or even ineffective if compared to the context in which it was planned. In order to understand these aspects, it is first necessary to explore the dynamics of escape in an emergency. This topic has been discussed and explored with increasing interest in recent years, precisely because the efficiency of the overall management system depends on it, and therefore on the fulfilment of the guarantee of the safety of the people involved during a fire. In fact, in the field of fire prevention, measures to help occupants escape are the most important for the safeguard of human life. Evacuation time is closely dependent on the human behaviour of the individual, but especially the group of individuals. To ensure effective occupant safety, it is necessary to understand the factors and conditions that influence human reactions. People, in an emergency context, make decisions that depend on a number of characteristics (both random and non-random).
Some of the main aspects that can have an effect in an emergency are: gender, age, physical capabilities, familiarity, social attachment, attachment to objects

Characteristics of the human being in an emergency situation

Any reality hosting a series of individuals constitutes an environment characterised by different peculiarities.
Building-occupant interaction is complex due to the particular nature of the occupants.
In addition to the ordinary alarm signalling, carried out by means of optical-acoustic systems, the procedures can assign a fundamental role to specially trained personnel during the evacuation phases.
Among the characteristics that influence behaviour and consequently choices during an emergency, in addition to those mentioned above, there are others that have a stronger impact on the dynamics of the escape. The evacuation, therefore, is influenced primarily by the type of users.

Gender
There are differences in behaviour between men and women. Men are more likely to try to help the other occupants and put out the fire, while women prefer to join the family and get to safety.

Age
Children have completely different reactions to emergencies in general from adults. Their particular behaviour is the result of their unawareness and inexperience. A child has a different perception of the risk from an adult. Older people may have little resistance to the debilitating effect of smoke and heat and may therefore be more exposed to risk.

Cultural aspects
There are other aspects that can have a major influence on the outcome of an evacuation. One of these is related to the concept of culture: people with different cultures may present different behaviours in an emergency situation. This aspect is related to the different perception of risk and is more evident in those contexts characterised by populations from more than one country.

Roles/responsibilities
The second important aspect is related to the roles and responsibilities of the occupant. Occupants with a higher hierarchical position are inclined to behave differently from occupants without responsibilities. Moreover, an incorrect action by one of them may compromise the life of a collective. This is the case of an employer or a teacher who must guide the entire class to the assembly point outside the building using

the escape routes determined in the evacuation plan. They also have to make almost instantaneous decisions when a specific escape route is obstructed or unavailable. It is precisely this latter situation that represents critical issues that can only be easily overcome through the promotion of safety concepts by making all the 'actors' involved prepared and aware.

Physical capabilities
Physical capabilities
People with physical and sensory disabilities slow down both their own and other people's evacuation.

Familiarities
Familiarities
In an emergency, individuals usually move towards familiar places or people. Familiarity in this case becomes a danger because the occupant does not really perceive danger by feeling in a safe environment.

Social attachment
Although people with social or affective attachments may help each other during an emergency situation, it is these attachments that slow down evacuation and reduce the perception of danger.

Attachment to objects
Before evacuating the building, some people tend to retrieve their personal belongings, even if this compromises or slows down their evacuation.

Each individual acts differently. Knowing the human factor in an emergency situation is essential to help improve the rescue operation and ensure the safety of the individuals involved.
Fire safety engineering and the tools that currently allow the design of safe environments require the development of a culture of fire safety awareness.
Information and education of the user are the tools that, together with engineering tools (which support the designer during the design phase) are able to guarantee an efficient and safe environment.
On the basis of what has been said, one can distinguish two main contexts involved that are needed to regulate and manage emergency situations:

- **the public sector**, which is educated and regulated through laws and regulations that manage public education and culture**;**
- **the private sector**, where training and company guidelines are essential.

Interaction between occupants and fire systems

Although it is possible to mitigate the influence of many of the above aspects of human behaviour in emergencies through the introduction of management solutions, there are others that require a different approach, because they are linked to a higher degree of uncertainty.
In order to take into account at least some of the behavioural and physical aspects mentioned above, research on the subject has proposed assigning movement speed values and pre-evacuation times for each type of occupant. The technical report ISO/TR 16738:2009 is the document that contains this information and aims to rationalise the data from the various studies on the subject so that it is available and usable by the community. It contains time and speed values to characterise occupant profiles. However, there are countless studies on the subject aimed at investigating these parameters.

The main fire protection regulations adopted by each country generally allow the use of data obtained from standards in force, but alternatively, they allow the designer to draw the input data for the escape modelling also from technical literature although the latter has scientific validity.
The interaction between the occupant and the environment is different depending on the configuration and the systems provided.
An example of this would be an optical-acoustic alarm with a multilingual message rather than an ordinary alarm.
This configuration allows the emergency status to be communicated to a larger range of occupants in conditions where the environment contains occupants of different cultures and languages.

EGRESS SIMULATIONS IN FIRE SCENARIOS

In the last decade, egress models used in fire engineering have increased their capabilities.
They started out as simple computational models based on equations related only to the hydraulics principles that implemented only small spaces. Subsequent developments have made it possible to simulate complex behaviours, such as decision-making through the most innovative simulation techniques. A great advantage of these automatic models is that they allow simulations to be repeated several times, thus making it possible to evaluate the best measures to adopt for the case examined by changing them and carrying out a simulation for each hypothesised scenario. In addition, the reiteration of simulations provides a better understanding of the dynamics of evacuation and a greater awareness of the phenomenon. An evacuation model is closer to reality than manual techniques. In order to understand the dynamics and characteristics of current evacuation models and their principles, it is first necessary to analyse the evolutionary process that they have undergone with the advancement of studies on human behaviour during emergency situations. The first scientific studies on evacuation simulations were carried out in the 1970s and 1980s. These studies represent the scientific basis on which all subsequent models have been founded. The RSET calculation was at first based on calculations using simple equations in which human behaviour was not taken into consideration and the movement of the occupants was approximated to that of a fluid. This principle assimilates the individual to a particle of fluid and approaches the subject with the rules of fluid dynamics. This resulted in the hydraulic model that still forms the basis of numerous techniques that attempt to simulate the movement of people and is based on the resolution of the Navier-Stokes fluid equations. A limitation of the RSET calculation based on the above-mentioned model is that it does not take behavioural aspects into account. The time includes not only the time required to reach the safe place, but also the additional time required for the so-called "decision-making process", i.e. the decision-related activity in the phase before the movement during the evacuation. Nowadays we are going through a phase of abandoning tools based only on equations and manual calculations, and research is focusing all energies on the study of agent-based models. ABM models allow the designer to establish certain behavioural rules to regulate the relationships between occupants and between occupants and their environment. However, it should be noted that not all factors influencing behaviour during evacuation activities have been investigated in detail, as studies carried out so far have not yet succeeded in characterising these processes from a mathematical aspect. This is mainly due to the fact that many aspects of human behaviour are entirely probabilistic and irrational, and therefore difficult to predict.

General aspects and characteristics of egress models

There are different models of egress simulation, and it is essential that the designer is trained on the subject and can accordingly select the most appropriate model for his or her needs.

A distinction should be made between simulation software and the evacuation models on which the former are based.
A number of scientific studies can be found in the literature with the aim of facilitating the choice of the model best suited to the requirements of the project under study.
These try to classify evacuation models according to their main characteristics.
One of these studies on this subject is represented by Kuligowski (2010), in which various aspects characterising these models are discussed and an attempt is made to provide classifications according to them. Further research on this subject was carried out in "Modeling crowd evacuation of a building based on seven methodological approaches" (Zheng et al., 2009). and "A review of optimisation models for pedestrian evacuation and design problems" (Vermuyten, 2016) in which the methodological approaches on which the models are based are classified and possible optimisations are discussed.
There are two methods for representing occupants within the model:

- **macroscopic models;**
- **microscopic models**.

Macroscopic models
In this approach, also called 'flow-based', the models represent people as one homogeneous group.
The occupants are not considered individually but are represented as a flow of a fluid in motion, omitting any distinction by individual.
Models employing these principles consist of a network, in which nodes identify building surfaces. The analogy allows the principles of fluids to be used, defining a density for the fluid.
These models are based on correlations between speed of movement and density, where for example there are narrowings in the escape path there will be decreases in flow.
Models that are based on the analogy between the flow of people and the flow of continuous media are also called "Continuum models" or "Fluid dynamics based models". They are characterized by relatively simple equations based on fluid theory. However, to date, this type of model has only been adopted by some simulation software. One of the main reasons why it is not widely used is that it is not able to describe the population in a real and heterogeneous way respecting the intrinsic and extrinsic characteristics of each occupant.

Microscopic models

In the microscopic model, occupants are considered as individuals with specific physical and behavioural properties, which makes it possible to best represent the characteristics of the population. In the evacuation model, people can perform actions given by means of behavioural rules. Examples include the possibility of reducing or increasing walking speed depending on the presence and the links with other occupants. This modelling approach is called 'Agent-Based Modeling' (ABM) and its applications range over many areas. Although they represent reality in a more complete way, as they are linked to the behavioural aspects of individuals, they are the subject of much research in order to obtain relationships and rules that can be implemented to describe the phenomenon of evacuation in a comprehensive way.
For the above-mentioned facts, the microscopic approach is the most widespread to date.

Modelling of geometries
Geometries to describe and represent the environment can be classified into three different types::

- course network;
- fine network;
- continuous.

The most popular models represent the environment by means of a continuous space in which the occupants are free to move. It follows that this model best approximates real movement.

Movement and behaviour modelling: the agent-based model

There are two main categories for describing the movement of occupants.The first category includes fluid dynamic models, which simulate the movement of a crowd as a fluid flow by solving the mode equations using the Navier-Stokes equations.Models of this type use differential equations to describe how density and velocity change with time. The need to be able to describe human behaviour in addition to movement has created the need for the development of new models. The agent-based model is a microscopic model that allows the simulation of very complex context. The system is modelled as a set of entities (agents) in which each of them behaves autonomously according to precise rules. Each agent is able to evaluate its conditions and make decisions about them by following the rules that have previously been implemented within the model. Many behavioural rules can be implemented within the ABM model.
The agent moves within the simulation in two steps: in the first step the individual recognises the context in which he or she is placed, after which in the second step he or she executes the rules predefined in the model for that specific situation. Although from a certain point of view the ABM model may seem simple as it consists entirely of agents and their relationships, it is able to represent complex behavioural patterns and provide information about the dynamics of the real system it simulates.
One of the characteristic aspects of this method is the bottom-up approach whereby the model considers the interactions of the individual elements of the system and then attempts to determine the special characteristics produced by these interactions. The interactions are repeated during the simulation with the consequence that the model becomes very computationally intensive compared to its competitors. The ABM model is the most widely used in current exodus simulation software, as it is very flexible and allows the heterogeneity of the population's behavioural characteristics to be described faithfully. This would be unthinkable if purely mathematical methods were used, which do not include a certain amount of repetition of interactions.
In summary, it can be said that the emergence of the ABM approach is linked to the fact that it allows the agent and the interactions between agents to be modelled in a flexible and optimised manner.
Within the world of agent-based models there are further classifications according to some characteristics. For instance, a first distinction can be made with reference to the level of "intelligence" of agents.
It is possible to obtain an occupant behaviour based on a decision process, i.e. the behaviour depends on the decisions made by the agents during the path. On the other hand, the path and objectives can be predefined and the agent will move within the environment avoiding collisions.

THE IMPLEMENTATION OF SIGNIFICANT PARAMETERS DURING AN EVACUATION WITHIN THE MODELS

The description of a fire scenario requires a complex model that simultaneously contains information on the development of the fire and the evolution of the escape dynamics.

The evolution of a fire is mainly described by the heat release rate (RHR curve) and the rate at which the products of combustion are released into the environment.

The effects of fire are generally assessed by measuring certain quantities to which occupants are subjected during their movement to a safe place.

International standards suggest the quantities used to perform this test. The values of visibility, temperature, radiation, FED/FEC are usually analysed.

The fire model, therefore, must interface with the egress model, making it possible to extrapolate the values to which users are subjected during the egress.

As with fire modelling (which is not the subject of this work), egress models also require the discretization of some values, mainly related to the factors that constitute the time required for an egress.

These values, as mentioned, are characterised by a strong randomness and make the escape model a complex environment to study.

The models allow the pre-evacuation times of the occupants to be entered according to a specific distribution. Consequently, the designer is able to assign the correct recognition and response times to each individual.

Some of the interaction between environment, fire effects and occupant can be predicted, such as the detection time and general alarm time.

However, there are dynamics that are difficult to predict, such as occupant-occupant interaction, where the behaviour of one individual may influence that of others.

A further limitation of escape models emerges when the study requires evaluating the effectiveness of one type of signage rather than a different type, or different acoustic alarms.

These aspects, together with those more related to wayfinding (which concerns the ability of a subject to move in an environment and reach a certain destination) are nowadays, with the current tools, difficult to interpret. As a result, virtual reality tools come to the help of taking a greater awareness of the designed buildings.

THE VIRTUAL ENVIRONMENT AS A VISUALISATION TOOL

The BIM (Building Information Modeling) methodology has introduced an innovative approach to design, increasingly moving the users of the process towards a three-dimensional, multidisciplinary and shared design, which also allows the storage of all the data and information of each object in the model. The BIM process aims to follow the construction of the building at every stage, from the design to its maintenance, becoming a fundamental part of the life of the building itself. The BIM methodology fits in perfectly with the latest visualization techniques, as it expresses its enormous potential there. The applications and uses of this approach, BIM+Fire simulation+Egress simulation+VR, represent a good method to qualitatively analyze fire scenarios and systems aimed at making occupants' evacuation more effective. In this chapter the concepts of virtual reality (immersive and non-immersive) and some applications will be introduced. Virtual Reality is a tool capable of faithfully reproducing a reality. Thanks to it, the user is completely immersed in a three-dimensional environment created specifically for this purpose. This approach involves all the senses, even those that are not usually stimulated, such as orientation, sight and hearing. The user can explore the environment and interact with it. To this category belong two different families according to the sensorial involvement of the user, that is immersive VR and non-immersive VR. In the first family (immersive VR) the user is totally isolated from the external environment and is therefore catapulted into a virtual environment entirely modelled by computer. The immersive experience is guaranteed by means of some peripherals that have the task of stimulating our senses. Mainly visors placed close to the eyes, also called HMDs (Head Mounted Displays) are used, which once worn immerse the wearer in a 360° visual experience. Together with these accessories, controls can also be provided, such as joysticks that allow movements and actions to be simulated with the hands. The non-immersive reality, on the other hand, includes technologies in which the artificially recreated environment has less of an emotional and sensory impact on the person. In this case, there is no possibility to interact with the environment but only a visual perception on the screen. In the engineering sector, virtual reality technologies can be used for different purposes. One of the main uses is in facility management, or to obtain information about the perception of brightness in rooms that have not yet been realised, or to present the project to the client, making them participate in the early stages of the design ("participatory design").VR devices can also be used to train specialised personnel for certain tasks that would otherwise be dangerous or time-consuming, as in the case of training firefighters in the use of particular fire extinguishing devices or emergency scenarios.

VR for Fire Safety Engineering

An interesting application of these tools is in the field of fire prevention. With the introduction and diffusion of Fire Safety Engineering methods in fire prevention design, the designer uses calculation models in order to assess the safety of occupants' by determining ASET (Available Safe Escape Time) and RSET (Required Safe Escape Time) values. These calculations require the use of software that allows fire simulation and building escape simulation. The outputs returned by this type of simulation are both quantitative and qualitative. In the case of a fire simulation, it is possible to assess the visibility at any point in the building, or rather visualise the spread of smoke in the volume and the fire.
The outputs of escape simulations generally consist of: crowd density maps, levels of service (LoS) of the various components of the escape route, graphs of evacuation times from the building or individual rooms, or even the calculation of the FED of each occupant.

From the combination of the egress and fire simulations the designer is able to evaluate the effectiveness of the fire protection measures planned in the project and, if necessary, optimise them appropriately.

The purpose of this contribution is to show how VR represents a direct support for several professional profiles in the field of fire prevention: the designer and the official of the assessment organisation (e.g. the Fire Brigade).

Specifically, the various opportunities that the applications shown in the contribution propose to provide to the end user are listed below:

- assist the designer during modelling in the design phase, in order to verify that the fire-fighting measures adopted for the case study are the optimal ones;
- extrapolate the time required to evacuate the building;
- verify that visibility reduced by the presence of smoke within the rooms does not compromise the safe exit of the occupants.

Occupant - environment interaction

Among the possible applications of virtual reality in the world of fire prevention there is the study of what is called "wayfinding". This contribution highlights the analysis using VR with reference to fire scenarios, focusing on the occupant/environment interaction and studying the impact of the escape system on people. Current international fire regulations define the characteristics of an effective escape system that communicates information to enable occupants to make the best decision to reach a safe location. At the moment no egress simulation software takes these aspects into account. For this reason, there is a need to analyse the interaction between escape systems and occupants, through the use of "first person" simulation tools. The objective of the application developed is to test the effectiveness of certain signage and alarm configurations in a typical office environment, while also assessing the impact they have on occupants. This aim is achieved through the creation of an app that allows people to immerse themselves in a real environment (recreated using BIM, Fire Safety Engineering and Virtual Reality modelling tools), including different configurations of signage systems inserted within fire scenarios that include the elements that characterise this type of event, such as smoke. Specifically, with the use of this tool it is proposed to evaluate exclusively the qualitative efficiency of the configurations of the signage systems, since, to date, the export of smoke is too complex. This obstacle does not allow quantitative evaluations to be made since, despite the fact that to recreate the smoke in the software used for Virtual Reality, reference is made to the visibility isosurfaces originating from fire simulations, the number of particles present in the environment, their size and the degree of obscuration that follows are not determined by computational fluid dynamics calculations. In order to achieve this goal, the authors have developed a tool which, by using the potential of tools based on reality simulation, will allow feedback from the people who will use it, so that evaluations can be made on signage, lighting and alarm systems in emergency situations.

The first step involves the creation of a 3D model using Autodesk's Revit software. The second step consists in designing the fire using FDS (Fire Dynamics Simulator), with which it is possible to carry out a fire simulation. Finally, the last step consists in the modelling in Unity - by Unity Technologies - a software able to develop interactive contents, with which the final application will be created, recreating the results obtained from the fluid dynamics simulation. In order to test the method, it was deemed appropriate to analyse a simple and complete case study, from which significant results can be extrapolated without necessarily having to reproduce a real case. The office designed is characterised by a single floor with a rectangular plan of approximately $230m^2$, with a central passage to each room.

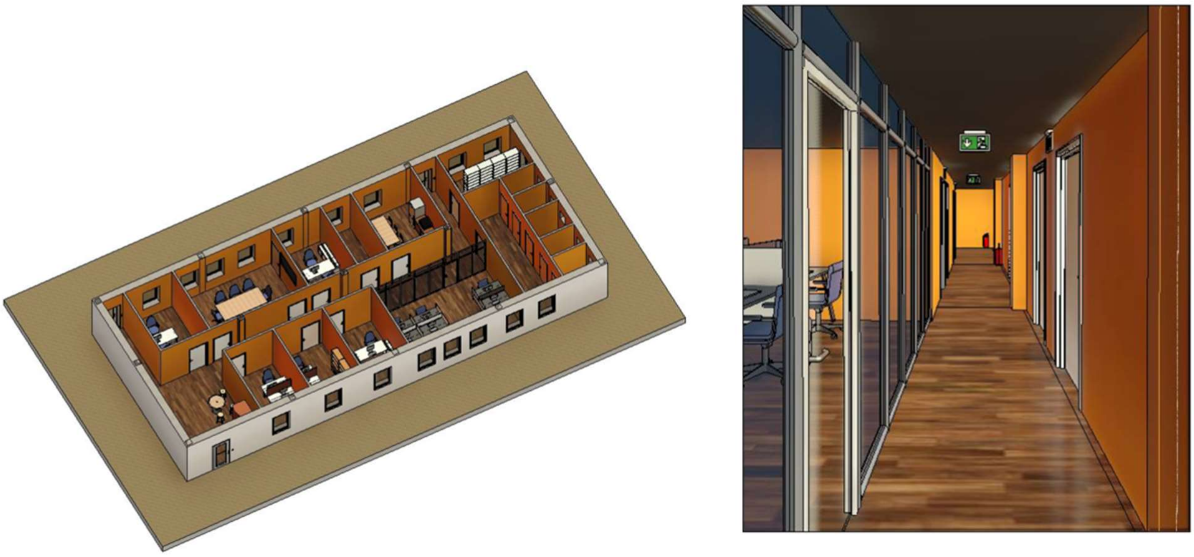

Figure 1. Interior view of modelled rooms

Modelled signage configurations

Seven scenarios were modelled. In particular, the first four scenarios study the effectiveness of lighting. Italian legislation imposes requirements on lighting, which must adequately illuminate escape routes and emergency signage. There is no requirement to use internally illuminated signs. What the authors set out to assess, in addition to the effectiveness of general lighting, is the effectiveness of backlit signage, comparing the two different types. At the same time, the first four scenarios assess the decision-making power of the occupant when faced with a sign indicating two different routes. The fifth scenario, on the other hand, was included to highlight the results of several studies showing that an alarm siren is less effective than a voice message. A further condition influencing wayfinding in an emergency is the way in which people are informed of the action to be taken. On several occasions, it has been shown that people respond very slowly to acoustic alarms (alarms, sirens, etc.), whereas they do not respond to information provided by voice messages with a higher information content.

In fact, knowledge reduces the possible manifestations of panic, enabling people to implement correct decision-making processes in relation to the conditions of the context in which they move. In these cases, verbal communication must be simple, direct and truthful: attempts to minimise the situation may cause confusion, preventing people from responding appropriately. The sixth scenario was used to assess the effectiveness of an escape route identification system. In this specific case, light strips were placed at the sides of the corridor to identify the spaces in the room. The seventh scenario concerns dynamic signage, i.e. that type of signage which, through the use of smoke detectors and temperature sensors, is able to establish the location of the fire and consequently modify the signage to allow occupants to reach a safe place without having to change route.

Figura 1. Scenario under ordinary conditions

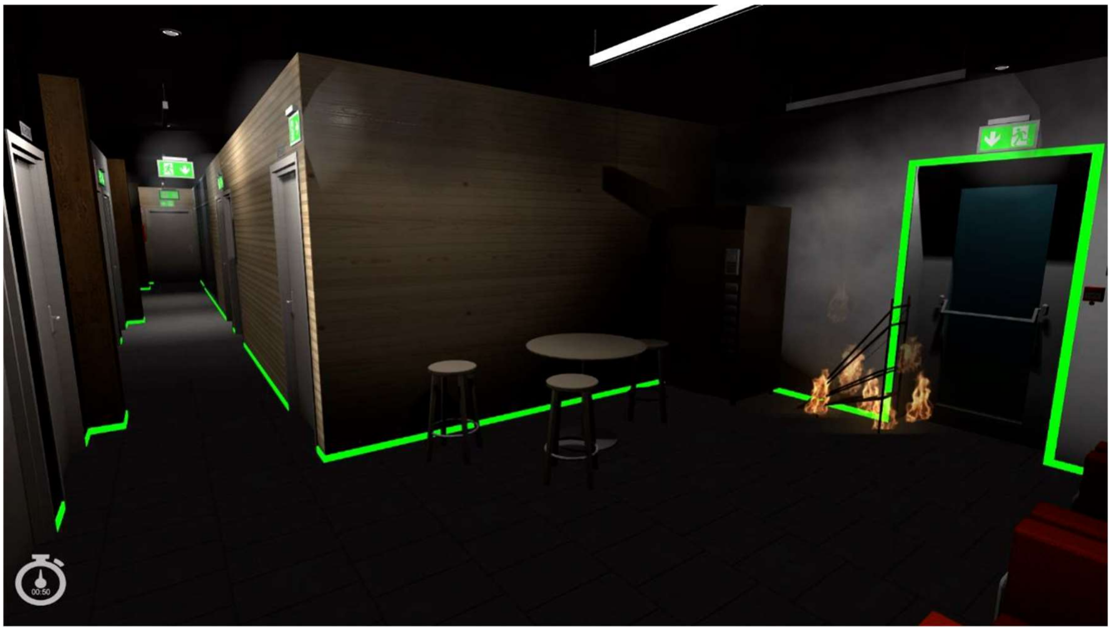

Figura 2. Emergency scenario

Data collection

In order to obtain feedback from the people who used the application, they were asked to answer a survey consisting of five sections: 1. General user information, 2. Evaluation of the tool, 3. Evaluation of scenario configurations, 5. Experience feedback.

From the feedback from the form, it appears that the application has been tried by a wide range of people, diversified in terms of gender, age and pre-knowledge on the topic.

The application thus made it possible to extrapolate feedback from users regarding the effectiveness of the type of signage used in the environment, but also regarding the timing of evacuations.
This demonstrates that similar tools are a real complement to the tools currently used for these purposes, providing added value in the design phase.

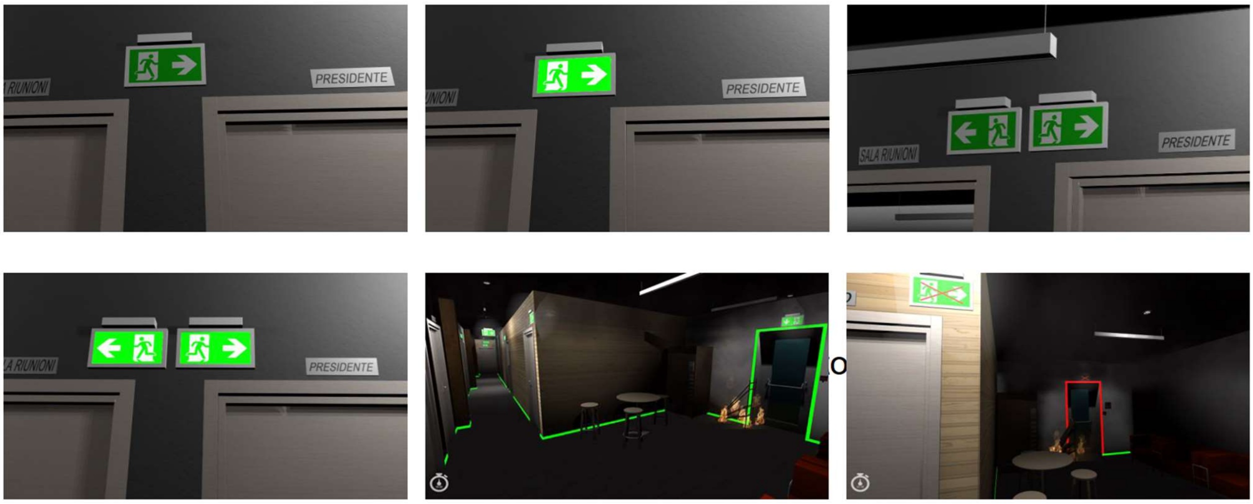

Figure 2. Modelled scenarios

Visualisation of simulations in a virtual environment

Understanding human behaviour in an emergency and studying the visibility of signage systems in the presence of smoke is essential to the study of escape in an emergency and therefore to ensuring the preservation of human life. In order to better understand and predict the dynamics of evacuation in an emergency context, it is essential to design an efficient escape system that allows the occupants to make the best decision to reach a safe place. Analyses were carried out to study fire simulation, using CFD software, and escape modelling, using numerical software. The work proposes a method for the export of the fire simulation and the escape simulation in virtual reality and the consequent visualization of them. In particular, the development of an interface is proposed that allows the control of the fire, the occupants, the signage systems and the design scenarios. The method provides an aid to research tools related to the world of Fire Safety Engineering and virtual reality.

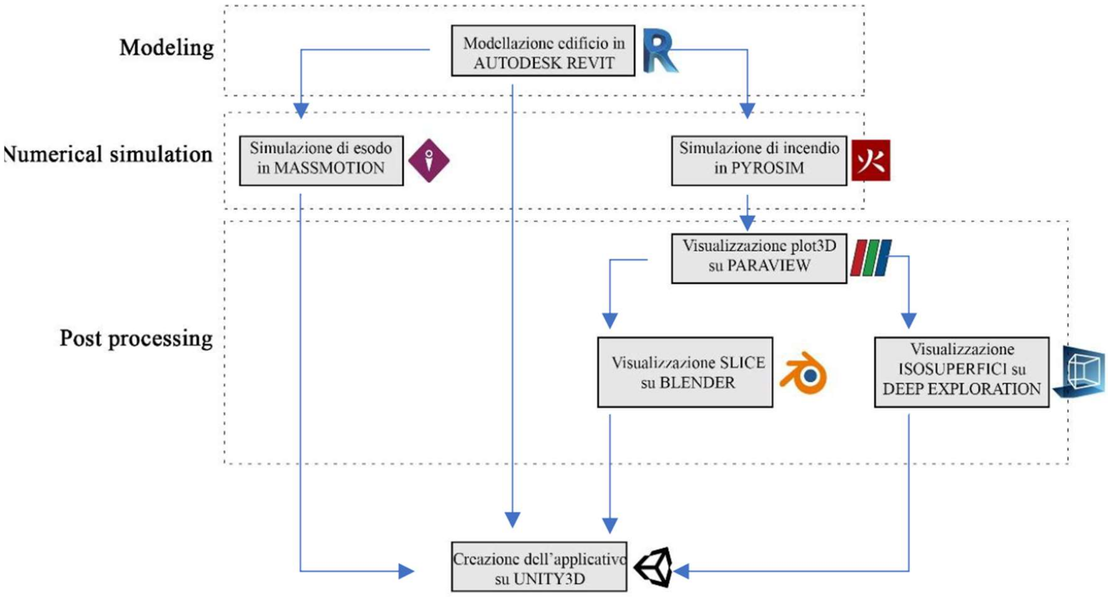

Figura 3. Methodology

The tool is designed to bring the world of Fire Safety Engineering into virtual reality by attempting to visualise the elements relating to escape and fire simulation. Signage is a fundamental component of building wayfinding and safety design.

The information communicated by the signs should clearly identify the direction and location of the means of escape from any point in the building to a safe place or final exit. It is often assumed that if the signage system is compliant, it will be effective in conveying information to occupants and that this will be correctly interpreted and used.

The application allows the results of fire and escape simulations to be obtained in a single environment. It allows the user to activate and deactivate the graphic display of some of the most significant quantities during the evaluation of a fire scenario. In particular, the user can display isosurfaces and slices of visibility and temperature.

As far as the egress simulation is concerned, the user is able to visualize the occupants in the model and follow their movements (it is possible to evaluate the influence that other occupants have on the user who is testing the application).

Finally, it is possible to choose which type of signage system to include in the model. The result is a configuration chosen by the user in terms of fire development, occupant egress and signage, which allows the user to assess the effectiveness of the system.

The aim of this contribution is to provide an alternative and more complete tool than those currently available, in order to immerse the user (the designer and the validator) within the simulation itself.

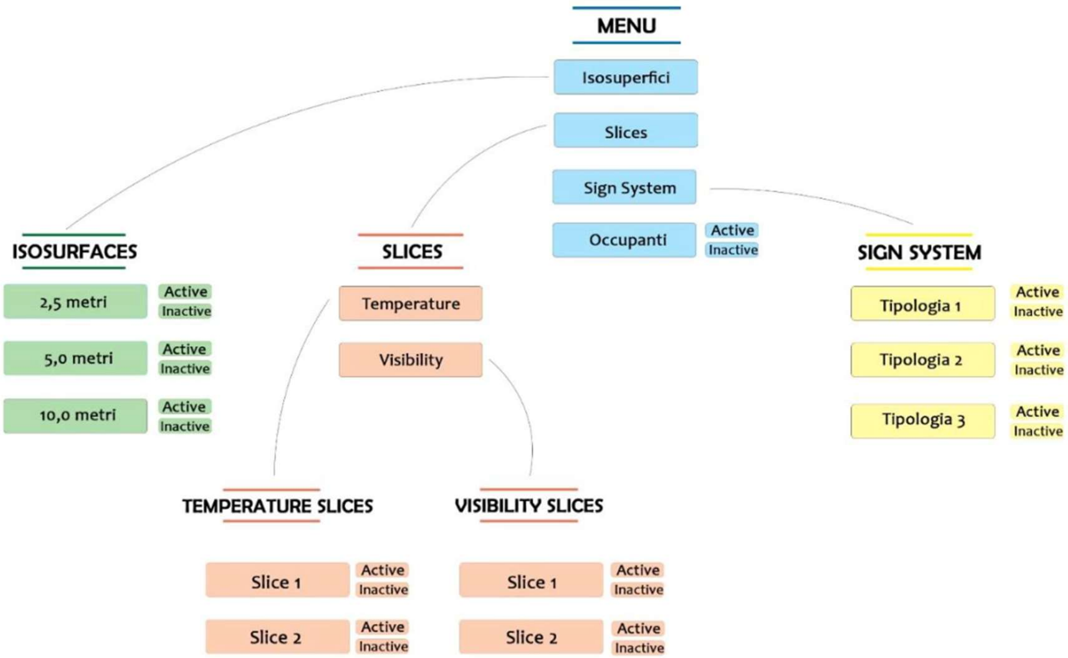

Figure 3. Parameters displayed in the model

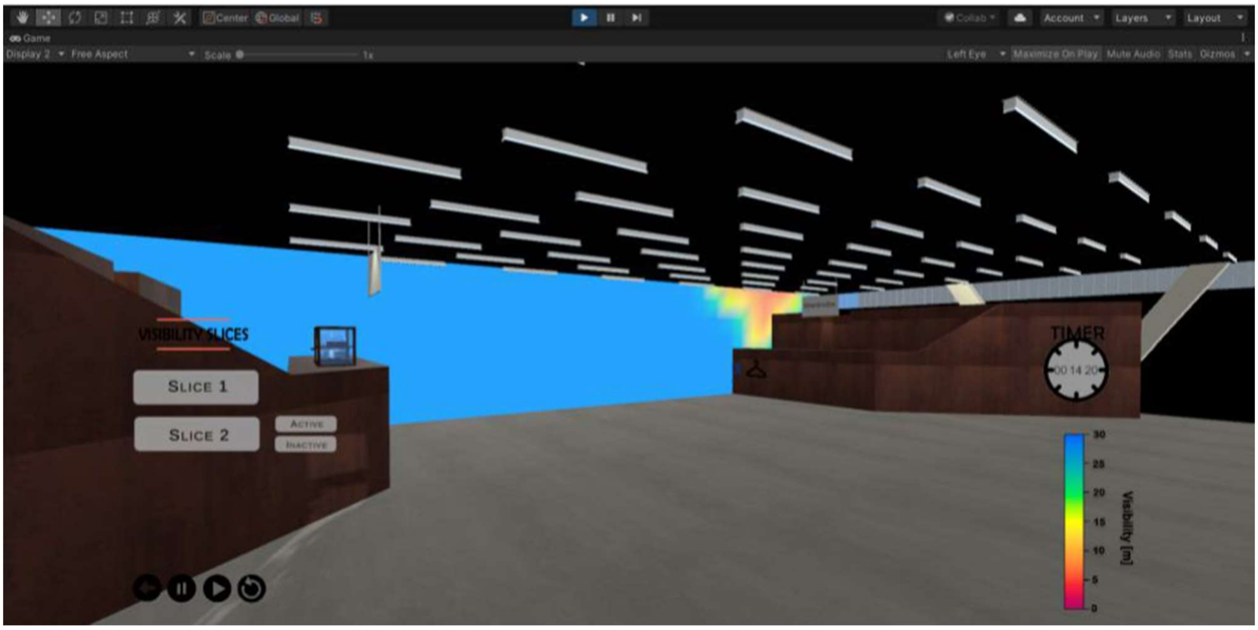

Figura 4. Model with visibility slice

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