



SEGURANÇA 4.0

Fire Modelling

Best Practices
Handbook



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V. 1.5c
Março 2023

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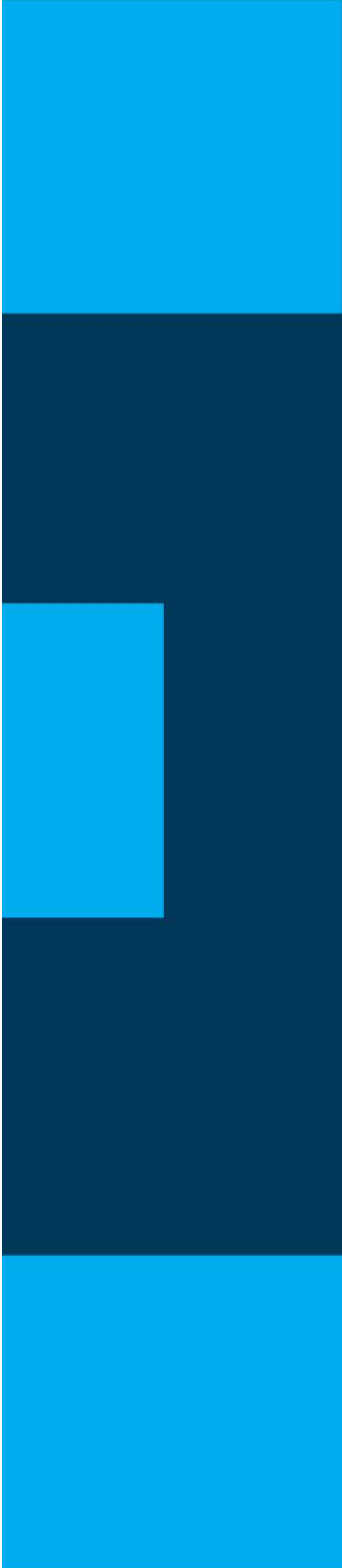
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01. introduction

1 introduction.

1.1 Scope

This manual is intended to provide a comprehensive and user-friendly overview of how to use fire modelling software in buildings. It is not (nor is it intended to be) a technical manual for using this type of tool, but rather a document to help the reader to understand the purpose of fire modelling software, to its advantages and limitations, and to help making decisions as to which calculation model to use in each situation. As it is also meant to provide methodologies and quality standards, it is called a best practices handbook.

1.2 What is fire modelling

Fire is a complex phenomenon, whose course depends on several factors, such as:

- Nature of the fire load (type of material, whether it is encapsulated or not, etc.)
- Fire load geometry
- Environmental conditions (temperature, humidity, pressure)
- Compartment characteristics (confined or unconfined, compartment geometry, thermal absorption of materials, etc.)
- Thermodynamics (fire-generated convection flows)
- Compartment fluid dynamics (smoke control systems, wind, etc.)
- Fire-fighting equipment available

The complexity of the phenomena and variables is such that it is hard to predict the course of a fire without software tools capable of processing all this information. Fire modelling software uses complex formulae to process the following types of information:

- Fire chemistry
- Fluid dynamics
- Thermodynamics
- Heat transfer

The calculations performed yield numerical information (tables) and graphical visualisations (2D and 3D images) of the development of the fire over time, to offer information such as:

- Height of smoke layer
- Temperature of smoke layer and smoke-free layer
- Optical density and visibility in smoke layer
- Chemical nature of gases in the compartment (oxygen content, carbon monoxide content, carbon dioxide and other reaction products) in both the smoke and smoke-free layer
- Gas flows through openings (air inlet and smoke outlet)
- Pressure gradients in the various compartments
- Temperature in compartment materials (walls, ceiling, floor)
- Radiation received at a specific point or surface

1.3 Purpose of fire modelling

Generally speaking, fire modelling is necessary whenever there is a need to predict how a fire will develop within a given compartment. Its applications are manifold:

- **Determine the fire resistance of structural elements**, allowing to predict the temperature to which they will be exposed and assess whether they will need passive protection, as well as the respective requirements
- **Check the tenability of the escape routes** over time (smoke height, temperature, toxicity, visibility, etc.); this is particularly useful in circumstances where the escape routes may be defective for some reason
- **Validate the effectiveness of the smoke control systems**; this is particularly relevant when the smoke control systems are not fully code compliant or where the characteristics of the compartment may cause the smoke control to be less effective, as in the case of particularly large or tall compartments
- **Analysis of fire and life safety design** whenever they do not fully comply with the regulatory requirements for any reason
- **Development of legislation**, allowing the legislator to validate whether the requirements it is providing for are efficient or excessive
- **Post-fire investigation** to model and understand what happened
- **Academic research**, which can be used to help interpreting the results of experimental work or to reduce the amount of experimental work required

In a business environment, fire modelling can be used in the following contexts:

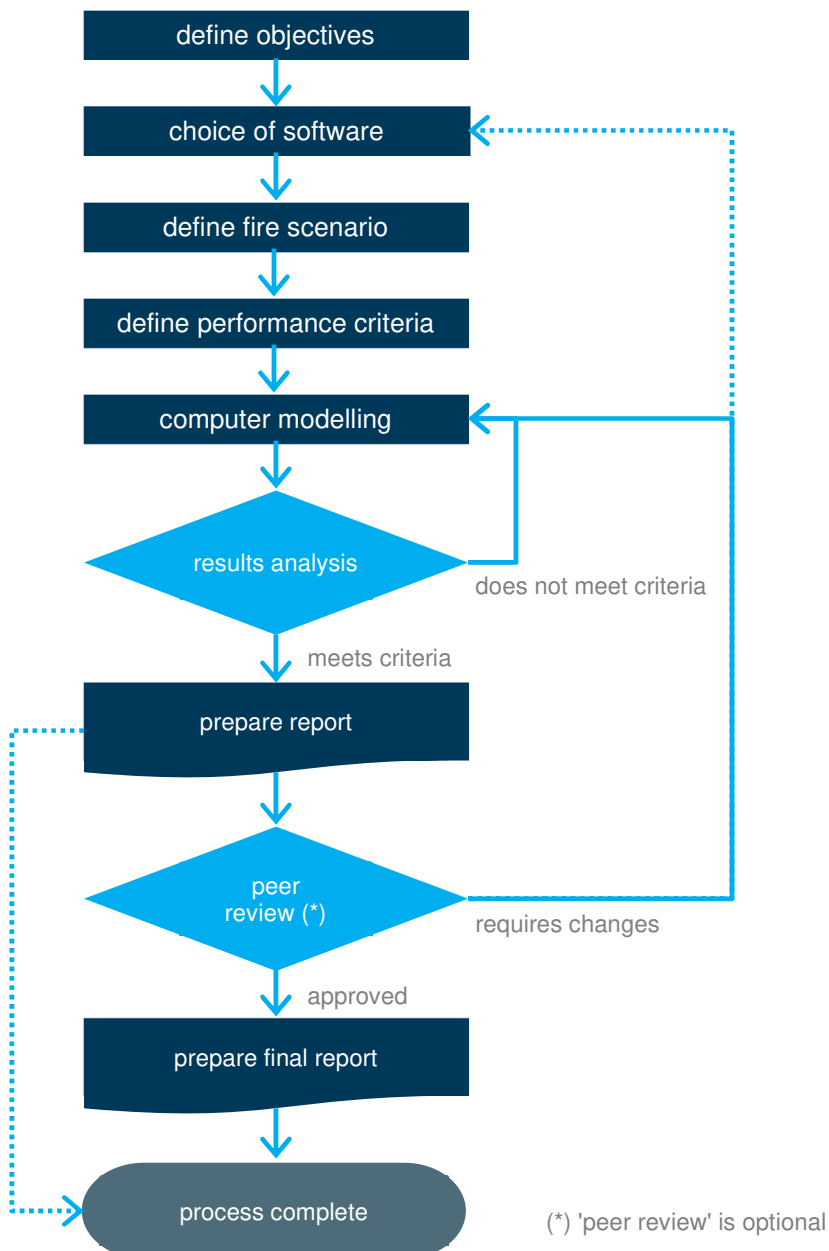
- Fire and life safety (F&LS) design
- Fire risk analysis
- Safety audits
- Safety management



02. **methodology**

2 methodology.

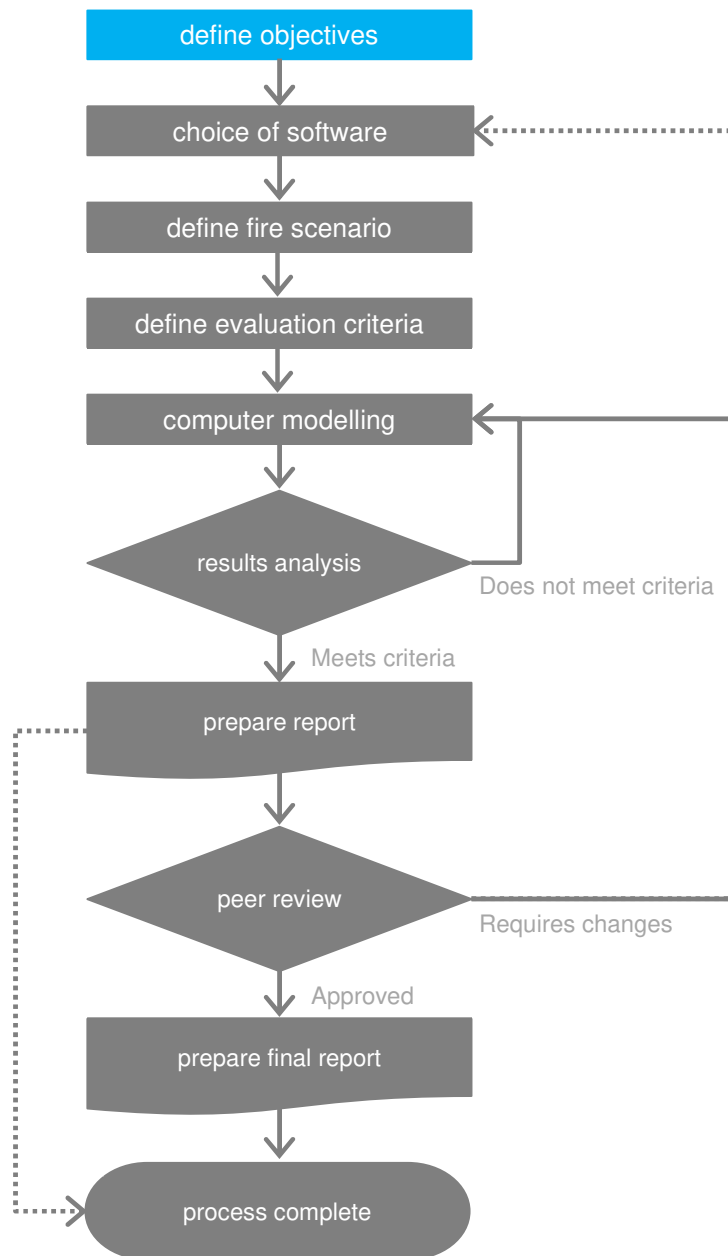
Like any other process, fire modelling must follow a certain procedure with several steps and tasks. The flow chart below depicts the usual procedure, and which needs to be adjusted on a case-by-case basis. Each of these steps will be described in a separate chapter in the following pages.



The methodology proposed above follows broadly the structure and rationale of ISO standard 23932:2009 *Fire safety engineering - General principles*.



03. **modelling objectives**



3 modelling objectives.

Defining the objective is the first step in the fire modelling process. As mentioned above, fire modelling can serve several purposes. Depending on the objective, there are different options as to the software, fire scenario and requirement criteria to be adopted.

Clearly defined objectives are of the essence to determine which resources will be needed, regardless of whether modelling is performed with internal company resources or using outside service providers. The tables below summarise the factors to take into consideration and provide a few examples.

Criterion	Example
Purpose	Determining the fire resistance of structural elements
Desired data	Temperatures in structural elements
Scope	Structural elements of a specific area
Addressee	Licensing authority / Contractor / Insurer
Peer review	No / University

Criterion	Example
Purpose	Check tenability of escape routes
Desired data	Smoke layer height and temperature, toxicity of gases, visibility
Scope	Categorisation of intended escape routes
Addressee	Licensing authority / Operating entity
Peer review	No

Criterion	Example
Purpose	Validate the effectiveness of smoke control systems in a car park
Desired data	Gas temperature at various heights, stream lines, visibility
Scope	Whole park, one floor only or one fire compartment only
Addressee	Licensing authority / Construction owner
Peer review	No / LNEC

Criterion	Example
Purpose	Post-fire investigation in case of fatalities
Desired data	Plume geometry, temperatures at specific (target) points, toxicity of gases
Scope	Compartments affected by fire and adjacent compartment that may bear an influence
Addressee	Insurance company / Legal entities
Peer review	No

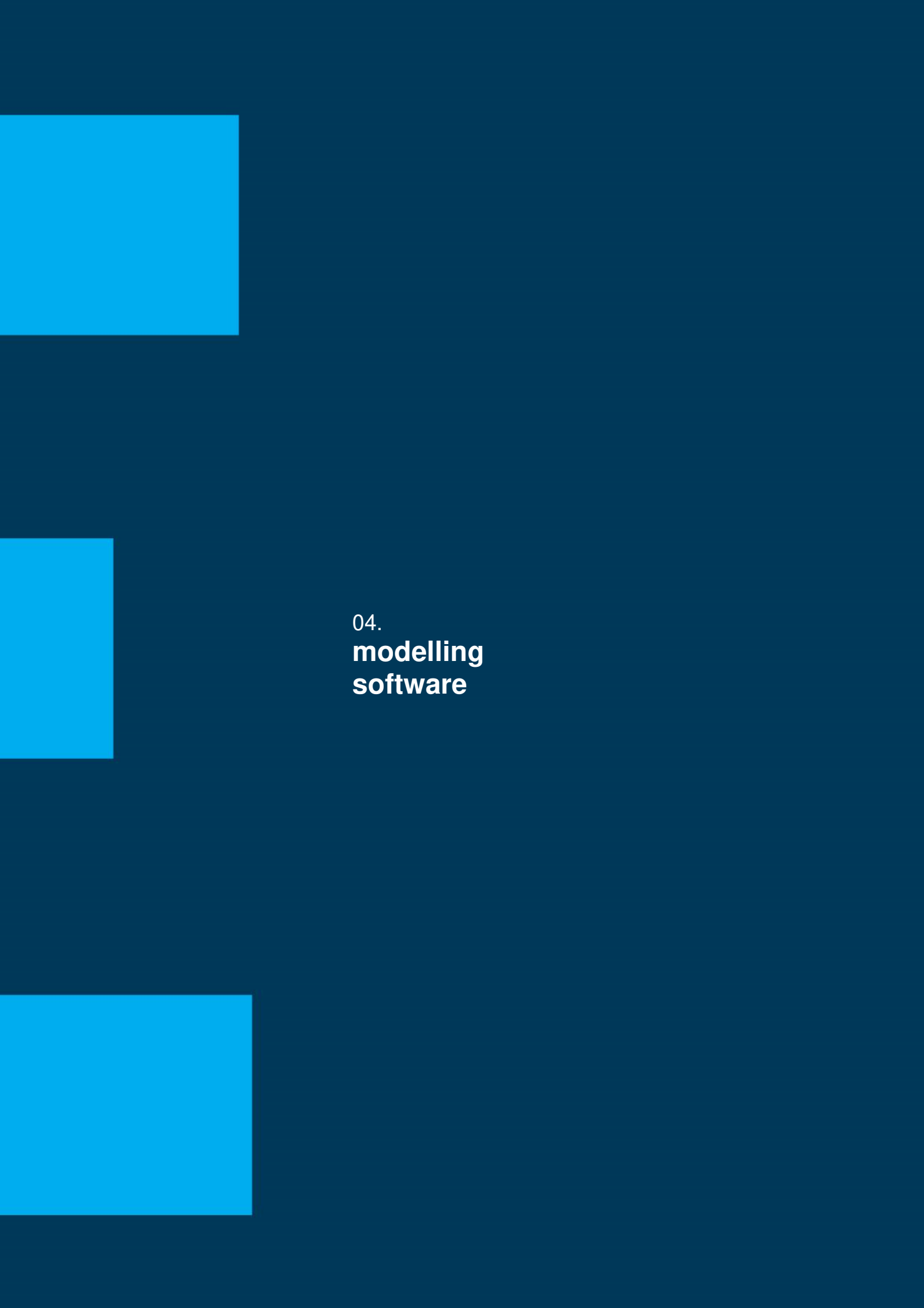
The purpose, intended data and scope are important when choosing the calculation model to be used when defining the fire scenario, choosing the required performance criteria, and deciding on the duration of the modelling run time. Knowing who the addressee is helps choosing the type of presentation (report, slide show, 3D animations) and the type of language (everyday language, accessible to all or technical, which may be less readily understandable). Finally, knowing whether there will be peer review allows you to predict the time needed for interaction with the reviewer and possible required changes to the model, if any.

Naturally, if the modelling is carried out by an external service provider, additional information must be provided to allow for assessing the complexity of the work, namely:

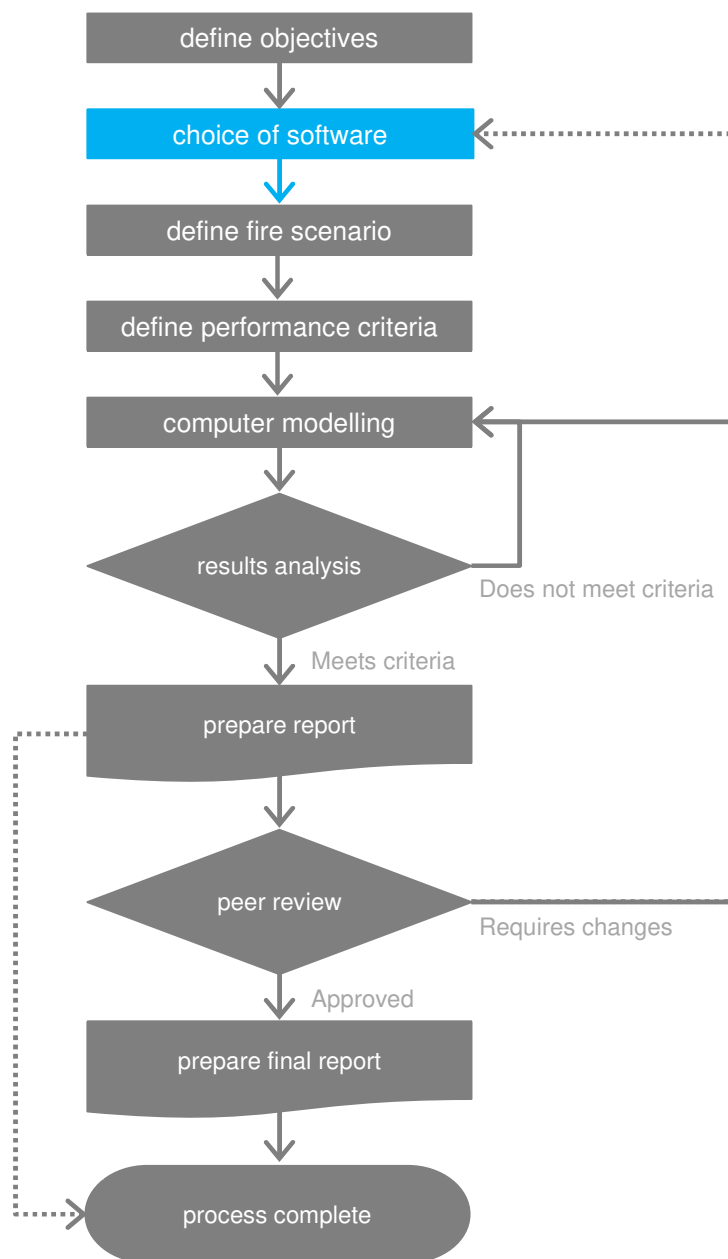
- Building occupancy type
- In the case of a warehouse, the nature of the fire load
- In the case of a factory, specific features of the manufacturing process that may be relevant to the progress of a fire
- Floor and other plans

Ideally, the definition of objectives should be done in conversation - informal if required - with all stakeholders, namely:

- Who will elaborate the modelling
- Addressee, especially if it is an official body (licensing authority, insurer, legal entity)
- Who will perform the review, if any

The background is a solid dark blue. There are three light blue rectangular blocks: one in the top-left corner, one in the middle-left area, and one in the bottom-left corner.

04. **modelling software**



4 modelling software.

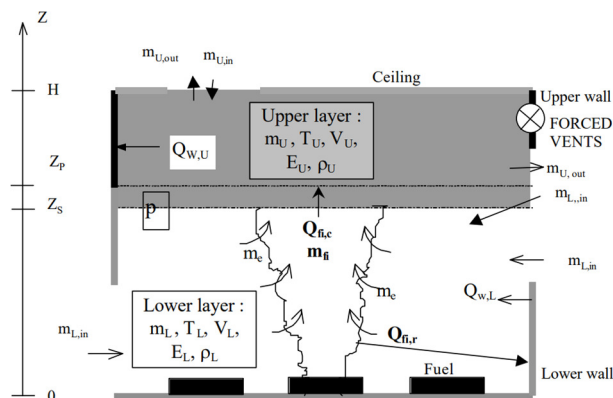
4.1 Software types

Several building fire modelling software are currently available on the market. Despite their diversity, they can be divided into two broad groups:

- Zone models
- Fluid dynamics models

Zone models

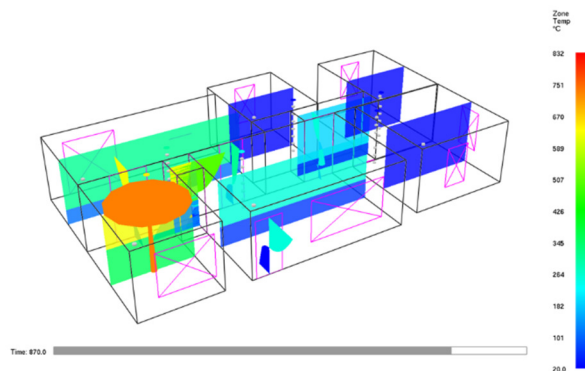
A zone model applies a simplified approach to the combustion phenomenology by considering that during a fire, gases stratify into two layers (or two zones), the upper one being the smoke layer (combustion gases) and the lower one the smoke-free layer (mainly air, but with other combustion gases). Although this approach is 'simplified', it is too complex for calculations to be done by hand or using spreadsheets. In fact, these models typically process eleven physical variables correlated via seven constraints and four differential equations continuously over time for both layers. These software allow to consider the exchange of gases through openings to the exterior or to other interior compartments, be they vertical (doors, windows) or horizontal (openings in slabs between floors or skylights). They also allow for contemplating mechanical ventilation devices for air supply and exhaust, thus enabling the modelling of smoke control systems.



Schematic section of a two-zone model and its various submodels. Ozone, Université de Liège

There are also simpler zone models, with only one zone for the total compartment volume, but as they are too rudimentary, they've mostly fallen out of use.

Software based on two zones allow for several volumes to be combined horizontally and vertically, which can form complex buildings with several hundred compartments and connections among them. Animated 3D visualisation of the model can be generated to show the evolution of the fire over time. They allow to visualise, for instance, the height of the various layers and their temperature and the flow of gases in the openings. It is also possible to consider multiple fire sources and include fire detectors, smoke control systems and, in some of the software, sprinklers. Command combinations can be created for triggering a succession of events, such as the activation of smoke control systems, or the opening and closing of doors and windows.

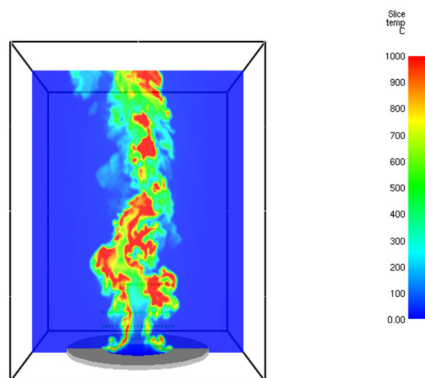


3D image of a three-bedroom flat. *CFAST, Nist*

In addition to 3D visualisation, these software can export a number of types of physical and chemical data, such as temperatures, pressure, radiation, gas flow rates through openings, chemical composition of gases, optical density, fuel consumed, among others. This data can be extracted for each compartment and each opening, and several probes (targets) can be placed in the compartments to acquire data such as temperature, radiation, and pressure. Examples of zone model-based software are CFAST by NIST, and OZone, developed by the University of Liège.

Fluid dynamics models

Computational Fluid Dynamics (CFD) models are highly complex in mathematical and computational terms. The fire compartments are subdivided into small cells (finite element models) to create a fine mesh. The software processes gas interactions between these cells over time, allowing for a much more detailed analysis of what is happening in the compartment, namely the gas turbulence. Rather than being flat and perfectly stratified as in the zone model, the smoke layer has a three-dimensional geometry that varies in time and space.



3D image of a methane flame showing temperature variation along the flame. *FDS, NIST*

These software allow for extracting the same type of data as the zone models, but in much greater detail. In addition, they also provide information on gas turbulence, e.g., providing a visualisation of the particle transport in gases (streamlines).

Examples of software using fluid dynamics models are FDS (Fire Dynamic Simulator) by NIST, and FLUENT created by Ansys. As the FDS interface is not particularly user-friendly (data is entered numerically), graphical interface software are available to simplify the data entry process, such as PyroSim by Thunderhead Engineering.

4.2 Validation

It is of utmost importance that the software to be used, regardless of being a zone model or a fluid dynamics model, is duly validated by a third party. This validation is normally done via full-scale tests to allow for ongoing calibration and improvement of the software. When choosing a modelling software, you should therefore consult available reference literature to make sure the software has been duly validated for the scenario to be modelled. All software referred to in this document meet these criteria.

4.3 Applicability limits

All software have an applicability limit. This limit may be the maximum number of rooms, maximum building size or number of fires. It is therefore important to check these limits in the software reference manual. For instance, when modelling the performance of automatic suppression systems, some software performs more rigorous and complex calculations that include all factors, while others resort to simplification, usually resulting in more conservative results.

4.4 Criteria for selection

The choice of software to be used for a given modelling depends on the objectives that have been set. The table below summarises the advantages and disadvantages of the different types of software.

Type	Advantages	Disadvantages
Zone models	Simple and fast modelling Fast processing Allows for modelling several fire scenarios in a short period of time Efficient and reliable for laminar flow	Does not import 3D geometry from other software Does not allow for creating complex geometries Not suitable for turbulent flow Limited ability to model wind action
Fluid dynamics models	Allows for creating complex geometries More detailed data, namely flame geometry and smoke layer Models fire in turbulent flow Allows for modelling phenomena other than fire, such as gas leaks or pollution	Very complex modelling Requires large computing resources, cloud computing recommended Modelling can take several days to complete

Based on these parameters, below are some examples of software depending on the objective.

Compartment type	Objective	Type of software to use
Storage room or small warehouse, connected to a corridor	Determine if a fire in this warehouse would jeopardise evacuation of the compartments enclosing the corridor	Zone model
A building with several small or medium-sized rooms, such as a hotel, hospital or school	Modelling of various fire scenarios, for the purpose of modelling the escape route tenability conditions	Zone model
Atrium with several geometrically not too complex levels	Modelling for quick determination of how efficient different types of smoke control are	Zone model
Geometrically very complex large-volume atrium with organic forms and sloping surfaces	Modelling of smoke control systems by dilution, requires checking the smoke toxicity toxicity at several different heights	Fluid dynamics model
Open large-area covered car park	Understanding whether wind action alone is sufficient to adequately remove the carbon monoxide	Fluid dynamics model
Car park with jet fans	Check performance of the smoke control system and the location of possible vortices where smoke may accumulate	Fluid dynamics model

4.5 Interaction with other types of software

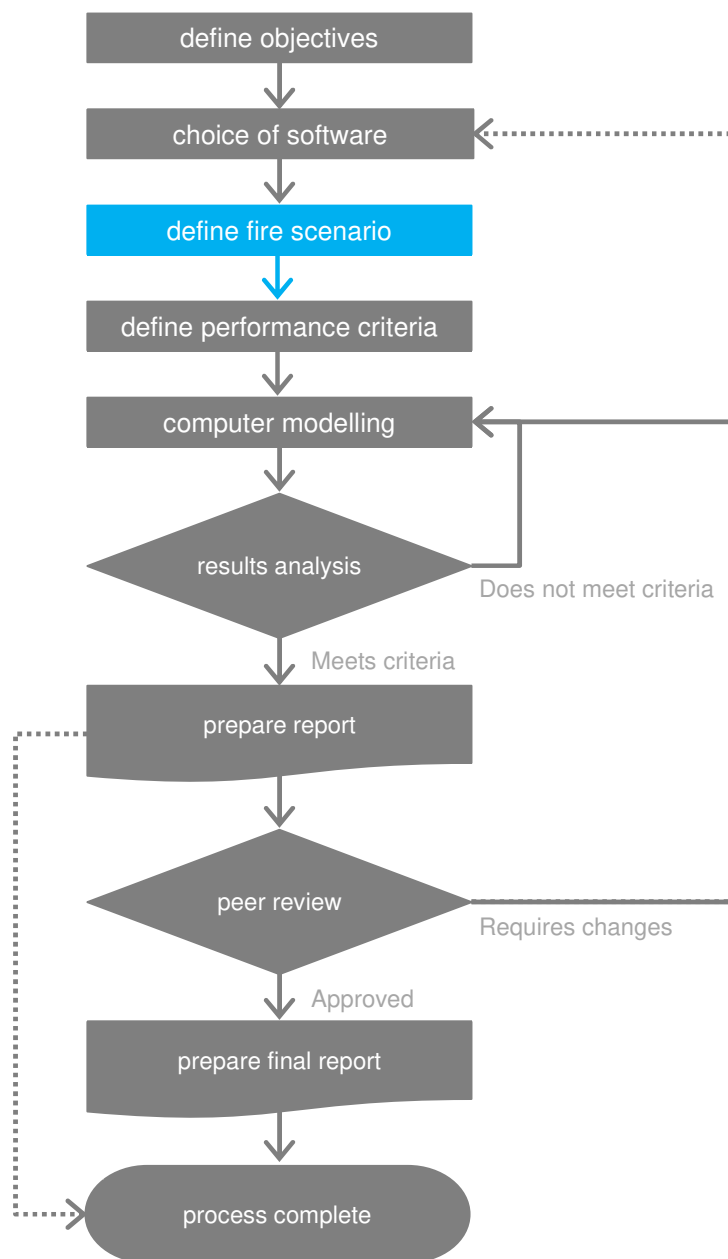
Another aspect that must be taken into consideration when choosing a software is a possible need for interaction with other types of software, whether for importing or exporting data, or for integrating data in real time.

For instance, when modelling a complex building that already exists as a three-dimensional BIM (Building Information Modeling) model, one would choose a software that can import that 3D geometry in a compatible format, the most common being IFC (International Foundation Class).

On the other hand, if for the building under study it is expected that it will be necessary to carry out fire and evacuation modelling to understand how the fire could affect the occupants, it is useful to choose a software that can integrate the result data of one model into the other. An example of this is PathFinder from Thunderhead Engineering, which allows the integration of FDS fire modelling results data.



05. **fire scenario**



5 fire scenario.

5.1 What is a fire scenario and what is it used for

A fire scenario is a set of assumptions that are taken into account when modelling fire, including definitions such as the following:

- Fire location
- Duration
- Design fire
- Active fire protection systems to be deployed
- Specificities arising from the operation of the building

Computer-based fire modelling can be a time-consuming process, especially if fluid dynamics models are used. Depending on the type of software used and the complexity of the building, processing a fire may take hours, days or even weeks. As such, it may not be feasible to model several different scenarios, and the scenarios that may be most challenging for the building in question will need to be determined.

5.2 Location of the fire

The location of the fire comprises two aspects:

- Compartment in which it occurs
- Specific location of the fire within the compartment

The choice of compartment depends very much on the objective set for the modelling. Examples of common scenarios:

- A. Room with highest occupancy load in the building (e.g., an auditorium)
- B. Critical areas in the evacuation paths of the building (e.g., an entrance hall)
- C. Tall high-volume compartment where smoke control may be less efficient due to its size
- D. Compartment on a very high floor above the reach of the fire engine ladders
- E. Compartment with highest fire load

Once the room where the fire will be modelled been determined, its location within that compartment needs to be defined. Bearing in mind that the scenario should be challenging, here are some possible locations for the examples above:

- A. Near the main door of the auditorium
- B. In a bottleneck area blocking the exit significantly
- C. Near an air supply ventilation grille
- D. Away from windows, so that they are not broken by the thermal action and do not ventilate the compartment
- E. In the middle of the compartment to maximise progression

5.3 Duration

Modelling a fire requires defining the duration during which the fire will be modelled. The longer the duration, the more hours (or even days!) will be needed for the computer to process the modelling. In order to speed up the process, the shortest possible duration serving the purpose of the modelling should be used. Examples:

- To model the evacuation tenability conditions - 15 minutes (assuming that evacuation is completed before that; the fire modelling time should always be longer than the estimated evacuation time)
- To predict environmental conditions when the fire brigade arrives - 30 minutes (if their arrival is expected much earlier)
- To assess impact on structural elements - 60 minutes or more, depending on evolution of fire curve and regulatory requirements for the compartment under analysis

5.4 Design fire

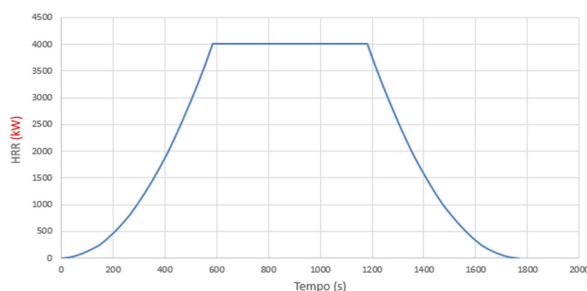
There are two possible methodologies for defining the design fire:

- If a given reference standard is to be followed, use the design fire specified in that standard
- Use a design fire matching the building's specificities

Standards usually typify situations, so a design fire may not be realistic for the compartment in question due to factors lacking or in excess. However, this approach is potentially more readily accepted by the licensing authorities.

The choice of a specific fire for the building may be a more appropriate solution, but it needs to be thoroughly substantiated via reference bibliography, and be reasonably conservative.

The graph below shows a sample fire curve, where the growth stage is a squared (αt^2) average growth reaching 1 MW at 300 seconds, as per Eurocode 1 - "Actions on structures", part 1-2 "General actions - Actions on structures exposed to fire" (EN 1991-1-2), followed by a steady burning stage of 4 MW, and finally a squared decay stage.



Fire growth and squared decay curve with a steady peak at 4 MW. Bruno Lopes

The definition of the design fire should cover several aspects. The most relevant ones are:

- Fire area
- Heat release rate

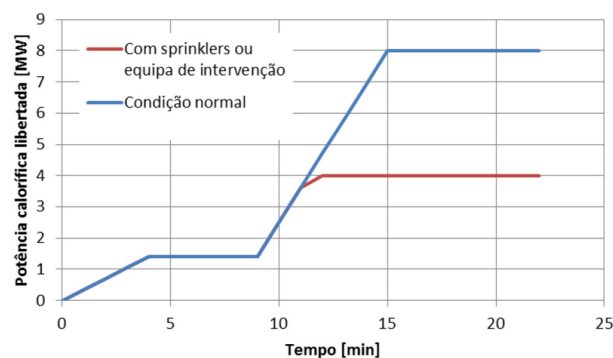
- Fire curve (development over time)
- Duration (which mayb be the result of combining the total energy released with the fire curve)
- Chemical composition of fire load
- Possibly relevant by-products, such as soot

The last two aspects are only really relevant if the modelling is for determining gas toxicity and visibility.

5.5 Active fire protection systems to be deployed

Active fire protection systems such as smoke control and automatic suppression systems have a significant impact on the fire that should be considered in the modelling. Most software allows for the model to be fitted with ventilation grilles, exhaust vents and mechanical ventilation or extraction devices. In fluid dynamics models, and unlike in in zone models, jet fans may be used.

The situation is somewhat more diverse when it comes to automatic suppression systems, where zone models are naturally more limited. However, even if the model does not have specific tools to handle suppression systems, their effect can be considered by using fire curves that already incorporate the heat release reduction resulting from their action. The graph below shows the example of a fire curve for cars, with and without sprinkler effect, as per Portuguese standard NP 4540:2015 '*Sistemas de ventilação de impulso em parques de estacionamento cobertos não compartimentados*' (Jet fans ventilation systems in non-compartmented covered car parks).



Car heat release rate fire curve, with or without sprinklers. NP 4540:2015

5.6 Specifics arising from the operation of the building

For the modelling to be realistic, its scenario should include any situation that could aggravate the fire and is considered very likely to occur.

For instance, when modelling a fire in a hotel room, it would not be logical to do it with the room door closed, as it would not significantly affect the corridor. Even if the room has fire resistant door with closer, the fire might occur while the room is being cleaned, with the door in an open position.

Another possible example is that of a fire in a nursery. The most critical moment for evacuation is probably during the children's nap time, when they are in their beds and caretakers are typically not in the room, but leave the door ajar. Modelling this scenario shows how the fire might affect the room where the children are sleeping if there is sufficient smoke in the corridor to spread into the room through the open door.

5.7 Opening of doors, windows, etc.

The opening of doors, windows, etc., especially to the outside, may affect development of the fire greatly since it significantly changes the evacuation conditions. A fire scenario should therefore take into consideration the following:

- The opening of doors by the occupants during evacuation; if the doors are equipped with closers, the opening and subsequent closing of the doors should be considered; if evacuation modelling is done, these data should be considered (which doors are opened/closed and when) and incorporated into the fire model
- Any windows that may be open at the start of the fire
- The breaking of window panes resulting from heat

It might be difficult to estimate the moment when glass breaks. This moment depends on several factors, including:

- Temperature difference between inside and outside
- Temperature difference between different parts of the glass if the neutral plane is at window height, the upper part of the glass being exposed to the hot gases of the smoke layer and the lower part to ambient temperature
- Temperature difference between the edge of the glass, which extends into the frame, and the visible portion of the glass that is exposed to environmental conditions; in general, the more efficient the heat transfer from the frame to the glass (e.g., in the case of older iron frames), the more easily the glass will shatter
- Characteristics of the glass, namely thickness, type (for instance, whether it is tempered or not) and if it is plain, double or laminated glass; for example, plain 3 mm glass (hardly used anymore, but often found in older buildings) will break at temperature differences around 150°C, while 6 mm or thicker double or laminated glass requires temperature differences of 650°C or more to break

There are some specific software for calculating glass breakage. Most of them will only specify at what point the first cracks occur, but not when the glass collapses or what the open area of the window will be, as the collapse may be partial. The collapse of glass after breakage also depends on several factors:

- The way the glass is attached to the frame; glass extending into frames with silicone sealing on both sides is more unlikely to collapse or at least collapse completely
- Size of glass; the larger the glass, the more likely it is that parts of the glass will fall out, especially around its centre
- Type of glass; tempered glass will take longer to break, but once it does, it is likely to do so completely

- Whether the glass is plain, double or laminated; double glazing is naturally less prone to collapse when the window is fully opened, as the collapsed part of the internal glass pane is unlikely to fully coincide with the collapsed part of the external glass pane
- Pressure differential between inside and outside; fires generate positive pressure so that the pressure on the glass can accelerate its collapse after cracking; for instance, this may happen with laminated glass; it should be noted that the pressure effect is only relevant for the collapse of the first window of the room, since afterwards the pressure in the room is relieved

Given the degree of uncertainty regarding glass breakage and collapse, it may be prudent to perform several modelling runs with closed and open windows and doors, and verify which scenario is the best option for the modelling objective. Example of correlation between objectives scenario of opening doors and/or windows:

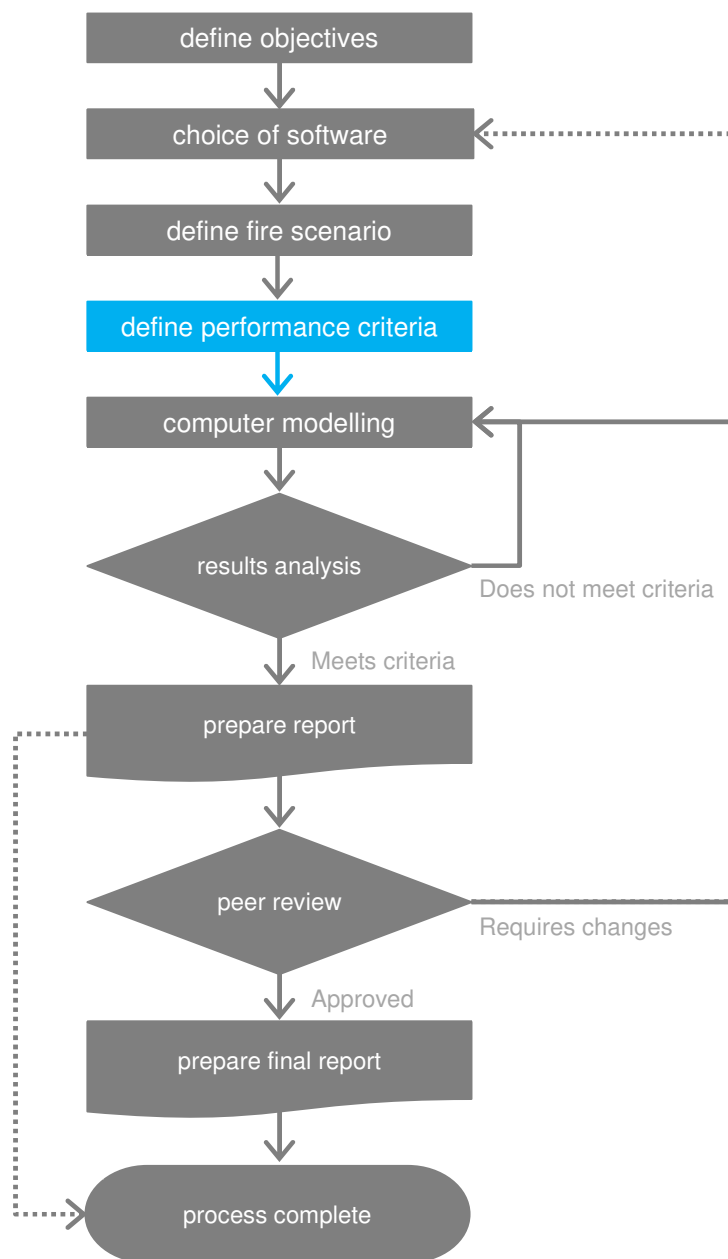
- If the objective is to model the fire resistance conditions of structural elements, a simulation considering all open doors/windows may be more challenging since oxygenation of the fire will give rise to much higher peak temperatures
- If the aim is to assess the evacuation conditions, a simulation with all windows to the outside closed and interior doors open (for instance, to the corridor) may be more suitable because while a fully developed fire will result in a lack of oxygen in the fire compartment, the temperature will be so high that pyrolysis will continue and a significant part of the combustion will occur when the gases reach the corridor rather than inside the compartment where the fire broke out; in this case, the fire temperature may be higher in the corridor (even when there is no fire load) than in the compartment where the fire broke out and where the fire load is located

5.8 Change of scenario

The fire scenario is chosen beforehand based on what is expected to be the most challenging case within the established objective. However, during the modelling process and according to the preliminary results, it may turn out that the scenario is less essential than initially expected, and that other situations may need to be examined. It may therefore be necessary to adjust or change the chosen scenario, something that should be considered as part of the normal process. Any changes to the fire scenario throughout the process should be referenced and duly justified in the modelling report.



06. performance criteria



6 performance criteria.

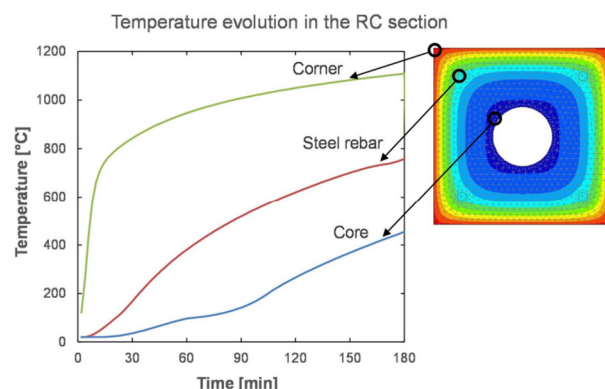
Determining the performance criteria is an important step in the process of computer-based fire modelling. These criteria must be chosen according to the objectives defined for the modelling and will subsequently determine the data to be extracted and analysed.

6.1 Fire behaviour of passive systems

If the objective is to model the performance of a passive system, the critical factor will be temperature. As such, the temperature that the structural element can withstand without collapsing needs to be known.

In the case of metallic elements, in which temperature distribution is reasonably uniform and without significant temperature gradients along their section, one speaks of 'critical temperature', given that thermal homogeneity across the section is assumed for reasons of simplification. However, for structural elements composed of various materials and with large sections, such as concrete structures, the temperature range along the section varies considerably, being higher at the edges and much lower in the central portion of the element, so that a critical temperature cannot be determined. In this case, the collapse will depend on the temperature reached in the rebar as well as on the number of rods that have reached a temperature at which they lose significant Loadbearing capacity.

It is important to understand that, up to the peak temperature of the fire, the gas temperature at the surface of structural elements is always considerably higher than the temperature of the structural elements themselves, i.e., the temperature of the structural element 'lags' behind the surrounding temperature. (Note: at an early stage in the temperature decrease of the fire, the temperature of the structural element exceeds the temperature of the gases around that element). The aforementioned lag is due to poor heat transfer between gases and solids, the higher or lower conductivity of the structural element material and the thermal inertia of the elements. As such, modelling the criteria considering only the temperature of the hot gases near the structural element is a rather conservative approach.



Temperature gradient in a concrete column and its evolution over time. *SAFIR Capabilities and examples of applications*

Finally, it should be noted that one of the possible approaches for modelling the structural fire resistance is to use a third-party structural fire modelling software such as SAFIR, developed by the University of Liège. Here, fire modelling is only used to generate temperature and radiation data for import into the structural modelling software.

6.2 Tenability of escape routes

If the modelling aim is to verify the tenability of escape routes, it is important to analyse the conditions to which the occupants will be exposed during evacuation. Conditions are influenced by several factors, such as:

- Gas temperature
- Gas composition, in particular oxygen content and toxic gases
- Amount of soot (to determine visibility)
- Radiation

These criteria should be based on legislation (no criteria are defined in Portugal), on reference standards or on specialised bibliography. Below you will find an example of the tenability criteria for healthy persons in Italian regulations (*Norme tecniche di prevenzione incendi*, 2011).

Tenability criteria	Applicable value for occupants
Height of smoke layer	≥ 2 m
Smoke layer temperature	$\leq 200^{\circ}\text{C}$
Temperature in smoke-free layer	$\leq 60^{\circ}\text{C}$
Radiant flux on occupants	$\leq 2,500$ W/m ²
Visibility within ignition site	≥ 5 m (checked at height of 1.8 m)
Visibility on escape routes	≥ 10 m (checked at height of 1.8 m)

As noted, the above values are applicable to healthy people. If the building in question houses a significant number of people with some type of weakness, namely patients (hospitals and nursing homes) or for whom no consolidated data is available (e.g., children under three), more conservative values should be used.

6.3 Firefighting

The above criteria apply to persons without any protective gear whatsoever. If one of the objectives of the modelling is to verify the operational firefighting conditions, it should be considered that firefighters wear thermal protective clothing and a SCBA (self-contained breathing apparatus). The tenability criteria to be applied in this case should consider the protection provided by these equipment. The table below presents the tenability criteria for firefighters, again using Italian regulations as an example.

Tenability criteria	Value to be considered for fire fighters
Height of smoke layer	≥ 1.5 m
Smoke layer temperature	$\leq 250^{\circ}\text{C}$
Temperature in smoke-free layer	$\leq 80^{\circ}\text{C}$
Radiant flux on occupants	$\leq 3,000$ W/m ²
Visibility within ignition site	≥ 2.5 m (checked at height of 1.8 m)
Visibility on escape routes	≥ 5 m (checked at height of 1.8 m)

Of course, this does not imply that firefighting is not possible under less favourable conditions or that firefighters are at risk if these values are exceeded. These values correspond to conditions allowing for firefighting to be carried out, and properly equipped firefighters can be exposed to them for periods of around 30 minutes.

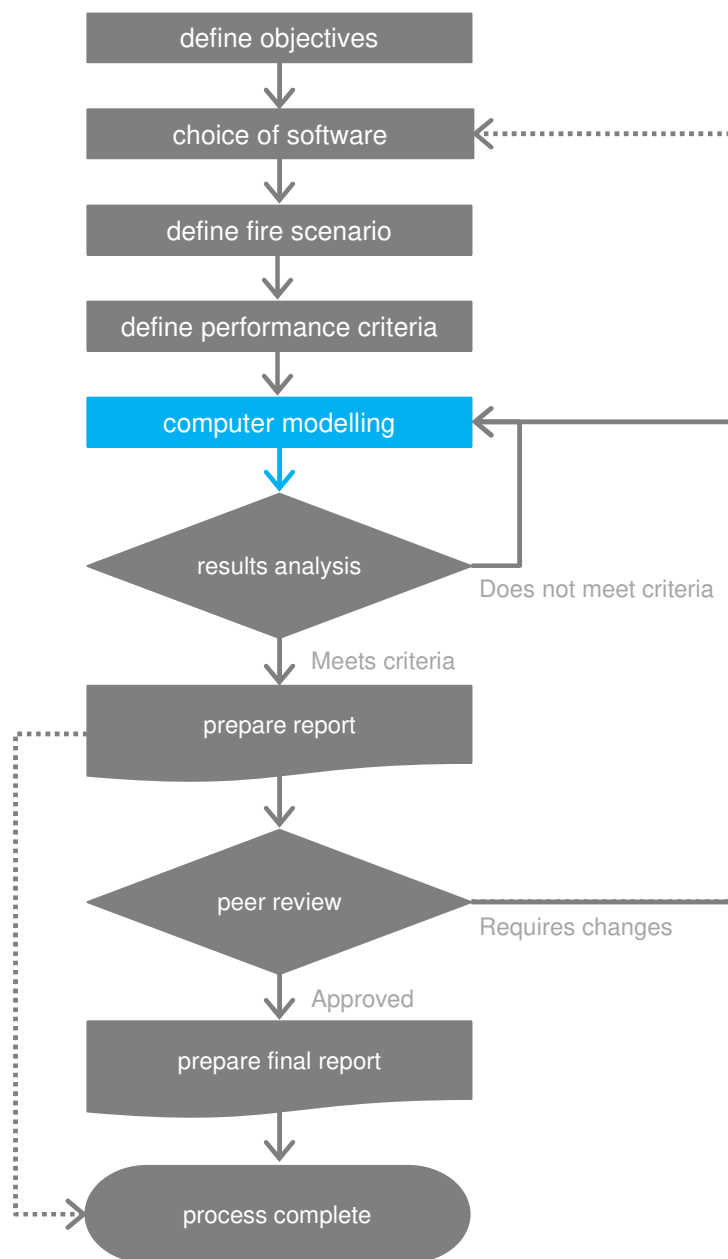
6.4 Modelling with no defined criteria

In some particular cases, it may not be necessary to set performance criteria. Examples:

- Fire modelling intended to provide data for third-party software, as mentioned above for the fire behavioural modelling software SAFIR
- Modelling performed to support post-fire investigation



07. **modelling**



7 modelling.

7.1 GIGO

GIGO stands for Garbage In, Garbage Out. This expression is used widely in IT to alert to the risk that if input is unreliable or incorrect data, the output will be equally incorrect. This concept applies even more so for fire modelling. Users must have thorough knowledge of the software they are working so as not to make mistakes. A common mistake is not to confirm in advance what measurement units the software uses, i.e., whether they are metric or imperial units. Another possibly less serious one is not to configure the environment modelling conditions (ambient temperature, relative air humidity, altitude) to match the building being studied. Examples of other aspects in which greatest thoroughness is required:

- If you are using a design fire curve other than the software's, the definition of this new fire curve should consider both the heat release rate over time, and the characteristics of the fire load (chemical composition, soot production)
- The enclosure materials (walls and slabs)
- When not using wall or slab materials from the software library, definition of the thermal properties of the new material

7.2 Building the model

The methodology and care to be taken in building the model vary greatly depending on the type of software used. However, there are recommendations that are common to all types of software:

- The volumes of the compartments should be as close as possible to reality, whereas architectural elements that do not interfere with the fire behaviour, such as pillars, railings and furniture, can be neglected
- The openings between the various compartments, and between these and the outside should be modelled accurately and without any simplification, as they are of great relevance to the modelling; for instance, a ceiling with four 1 by 1 metre extractors must never be simplified down to a single 2 by 2 metre extractor, even though the area is exactly the same as regards aerodynamics, both cases behave differently, and a larger-area extractor may become less efficient due to a plug-hole effect (inverse eddying in the smoke layer causing the central part of the extractors to extract air from the smoke-free layer rather than smoke)
- Great care should be taken in the characterisation of the compartment materials, in particular walls and ceilings, since they can affect the temperatures reached

Zone models

In zone models, compartments are simplified into parallelepiped volumes. A compartment with a trapezoid floor plan can be simplified using a single volume of equal area and height (and as such the same volume) or by adjoining several connected volumes into a combined shape with an approximate equal volume. Here it is critical that the sum of the volumes is identical to the volume of the original compartment.

When a compartment has beams forming smoke reservoirs, multiple volumes need to be created, one for each reservoir for the modelling to consider the effect of the beams on smoke propagation along the ceiling. Similarly, if the compartment has varying heights in different parts, a volume needs to be created for each of these areas to link the various volumes together.

Most zone model software can also consider rooms with a tapering ceiling, i.e., that is narrower at the top than at the bottom (such as a dome or a vault), and a section that varies over its height can be defined.

Fluid dynamics models

Fluid dynamics software requires no significant volumetric simplifications, even in software where compartments are constructed according to a parallelepiped mesh. A critical factor in the construction of the model is the definition of the mesh size. Typical values for mesh size range from 3 cm to 30 cm. While too fine a mesh provides more accurate results, processing time will increase significantly as the calculations are performed volume by volume of the mesh. A 30 by 30 cm cube can fit 1,000 cubes of 3 by 3 cm, so a 3 by 3 cm mesh requires a thousand times more calculation than a 30 cm grid. The meshes can be variable, being thinner in the fire zone and widening as distance increases, but the different meshes must be multiples of each other.

Most fluid-dynamics based fire modelling software support import of 3D models from other software, namely from BIM (Building Information Modeling) software such as Autodesk Revit or others. Import is typically done using the interoperable IFC (Industry Foundation Classes) file format, which is compatible with most software requiring 3D models. In addition to geometry, and if so configured, IFC can also export the physical properties of the materials (walls, slabs, openings), which can then be imported into the fire modelling software.

Importing the 3D model from other software can save many hours of modelling, but it is often not entirely straightforward, and some adjustments need to be made. For instance, in buildings with complex geometries, such as curved surfaces and numerous sloping planes, the conversion to software that work with a parallelepiped mesh can result in buildings with gaps in the walls, through which air can leak. A good way of detecting these types of faults is to pressurise the building and analyse the air flows to spot holes in the geometry. Another common problem is when the modelling software does not recognise openings, so some modelling work may be required in the fire modelling software.

Since exporting and subsequent importing are often slow and error-prone, especially for complex models, the 3D model should be simplified before exporting. When using BIM models, the best way is to export only the architectural geometry as well as possibly the structural geometry, but no furniture, hydraulics, electric systems, HVAC and so forth. If the fire scenario is in a localised area of the building (as happens most of the time), only the part of the geometry that will be used in the modelling software should be imported.

7.3 Implementating the fire scenario

Once the geometry of the building or part of the building under study has been created, the next steps of implementing the fire scenario in the model can be tackled. This includes in particular:

- Setting the environmental conditions (ambient temperature, relative humidity, altitude, wind outside, etc.) in case the software's default conditions are not used.
- Inserting the fire or fires to be used in the model as per the defined scenario
- Inserting the various active and passive systems of the scenario into the model, defining not only their properties (areas, flows, pressures, etc.), but also their trigger conditions (temperature, time, etc.)
- Inserting data acquisition points (targets) in the model if the modelling objective requires specific information, e.g., if the objective is to model structural resistance in a fire situation, temperature data on the surface of structural elements will need to be collected

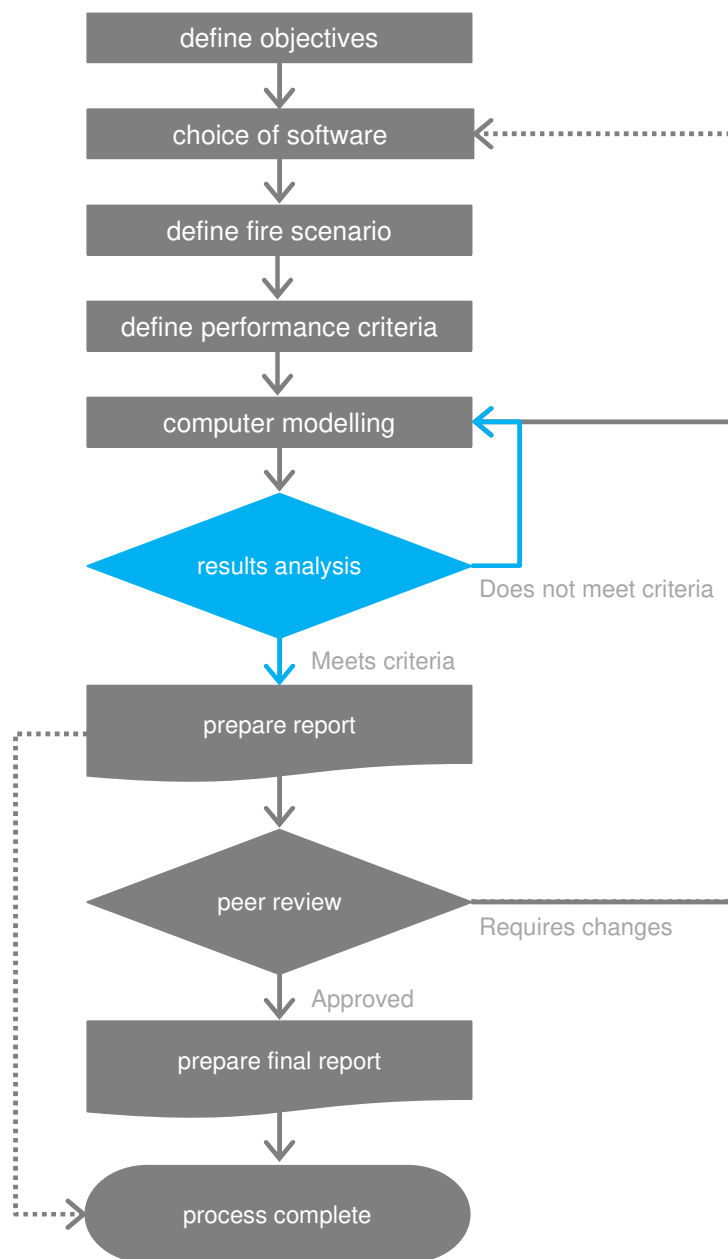
7.4 Processing

After completing the previous tasks, the actual modelling can now be run in the software. While processing in zone model software is usually done in a matter of minutes, fluid dynamics-based software it may take hours or even several days, depending on the complexity of the model.

To shorten modelling time, most fluid dynamics-based software can be run on multiple networked computers, and some companies provide cloud computing services, with processors being rented by the hour. The modelling process can also be split across multiple processor cores, ensuring that each part of the model has more or less the same number of finite elements. As processing needs to be done concurrently for all parts, if one part has many elements and another only a few, the larger part will be processed more slowly, thereby constraining processing of the other parts.

Model duration is equally critical in terms of processing time. As such, the duration chosen should be the shortest possible to allow for achieving the intended goal. Modelling evacuation tenability may only require 15 minutes, but modelling the fire behaviour of structural elements can take an hour or longer.

08.
results analysis



8 results analysis.

8.1 Data preparation

Modelling software generate a significant amount of data. Several types of data for each compartment (height of smoke layer, temperature in and below smoke layer, pressure, radiant flux over floor, etc.) are typically generated, and the same applies to openings (flow above and below neutral plane, velocity above and below neutral plane, pressure differences, etc.). All data is generated at short intervals over time (for instance, every 5 seconds). The information is usually provided in a CSV (comma-separated values) text file.

The data is normally processed and analysed in spreadsheet software such as Excel, which is capable of importing CSV files and organising the information into easy-to-read tables and graphs. Most modelling software splits the data into different files (e.g., one for compartment data, another one for fire data and yet another one for gas flows), and the information within each file is divided into groups (e.g., extractors, fans, etc.). The intended information must be selected bearing based on the objective of the modelling and the specified criteria, importing only what is needed for that objective, and deleting any data not deemed to be necessary. The data analysed will typically only be a small percentage (1% or less) of the data generated by the software.

The spreadsheets are used for analysing numerical information. However, an animated 3D visualisation of the results can only be produced in specialised software like NIST Smokeview, which allows for visualising both CFAST (zone) models and FDS (fluid dynamics) models. As mentioned above, modelling software generates a huge amount of data, enabling visualisation software to generate numerous different 3D views, such as smoke optical density, visibility, gas temperature, gas flows (including direction and velocity), etc. These software provide a quick and intuitive view of the results, and the visualisations can be exported to movie formats using an actual movie format such as MOV, or compiling sequential images (JPG or similar) into a movie using third-party video editing software.

8.2 Integration of information from other modelling software

Depending on the purpose of the modelling, data from other modelling software may also be included for combined analysis. This will be the case when the tenability of evacuation is to be verified by cross-checking fire modelling data against data generated by evacuation modelling software. Both software types generate CSV data and use the same time format, and all that needs to be done in both software (fire and evacuation) is to define the same time interval for the data export (e.g., 5 second intervals).

Data from both software can be combined in the same spreadsheet to be, for instance, displayed side by side or to visualise the evolution of the environmental conditions in a room and the number of people in a room within the same graph.

Finally, some software can also combine results from different software into a single visualisation. For instance, if the evacuation is modelled in PathFinder, a 3D animation visualisation can be created showing the people being evacuated, combined with information from the fire modelling in the FDS software.



3D visualisation of evacuation combined with fire. *Pathfinder Features*

8.3 Performance assessment

The modelling results should be compared with the performance criteria established initially. When the criteria are not met, the deviation should be analysed and possible strategies for amendment defined, namely modifying the planned passive and active resources. The solutions found should be validated through repeated modelling until the results meet the established criteria.

In some situations, it may happen that no viable solution can be found for the required criteria. In such circumstances, there are several possibilities:

- Re-evaluate if the fire scenario, namely the design fire, is not too conservative or excessive
- Revisit the performance criteria to make sure they are not too conservative or possibly excessive either; for instance, there are normative references for the height of the smoke layer referring to a height of 2.5 m (ISO TR 16738, Singapore regulation), others of 2.0 m (Italian regulation, Australian regulation), others of 1.5 m (NFPA 101) and others still, has a function of the compartment height, expressed by a formula such as $1.6 + 0.1 \times h$, where h is the ceiling height (INSTA TS 950 standard, from Nordic countries). Whichever the case, only one reference must be chosen rather than multiple criteria from different sources
- Acknowledge that there is no feasible active or passive solution that can make the building meet the performance criteria, and a different approach must be made using measures other than active or passive, such as partial usage restriction

Any change in the scenario or performance criteria must be duly documented and justified in the report in a fully transparent manner.

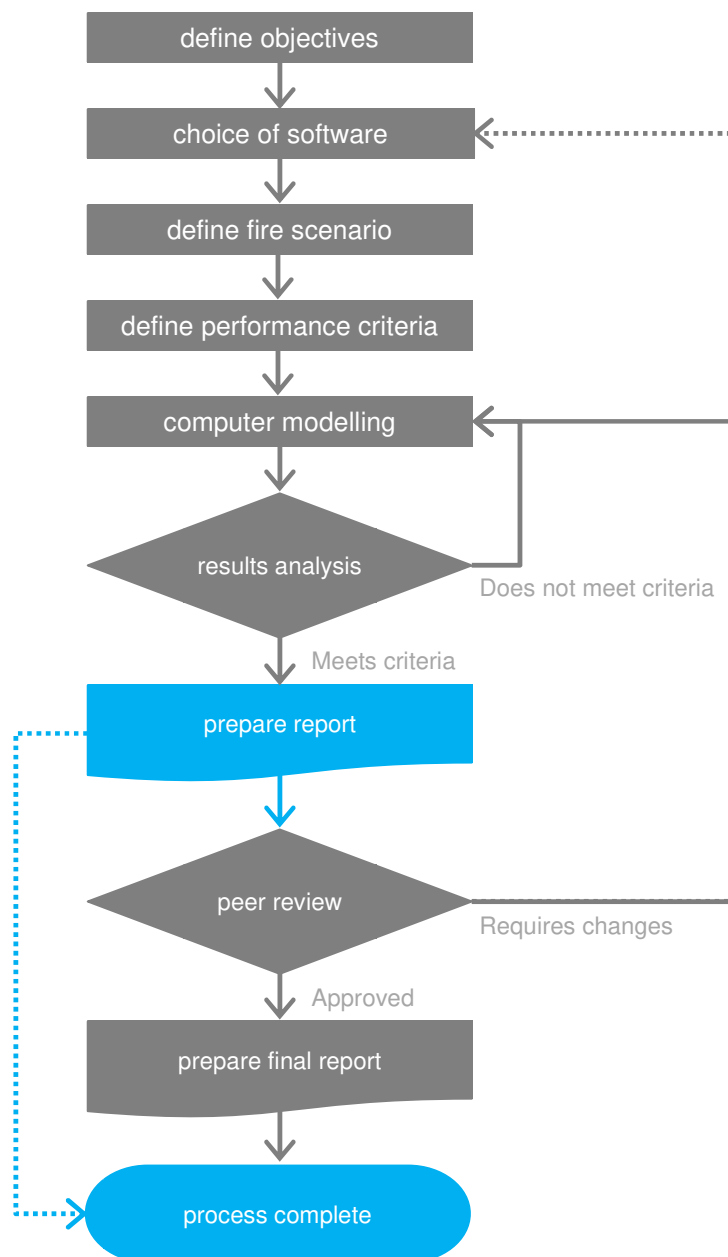
8.4 Safety margin

All assessment needs to include a safety margin to minimize the risk related with uncertainties. This safety margin is sometimes defined in the fire codes (not covered in Portuguese regulations), and varies typically

between 1.2 and 2.0 applied over the evacuation time. For instance, to verify the evacuation tenability conditions, the Available Safe Evacuation Time (ASET), in which conditions for evacuation are good (according to the chosen criteria) must be at least 1.2 times greater than the Required Safe Egress Time (RSET), that is the time actually needed for evacuation. The RSET should be determined by calculation or evacuation modelling.

The definition of the safety coefficient within the above-mentioned range needs to reflect the existing degree of uncertainty. Typically, a value of 1.2 will be used for fully compliant buildings or buildings with full sprinkler coverage (whether mandatory or not). If the building has major non-compliances or weaknesses, or if there are circumstances for which no consolidated technical and scientific knowledge is available (e.g., tenability criteria for the elderly), this value should be higher, up to 2.0. The coefficient used should be properly justified in the report.

09.
report



9 report.

The modelling report is an important part of any minimally formal modelling process. An example of this is the modelling of a car park fire with jet fans to be attached to the fire and life safety (F&LS) project or the specific smoke control project.

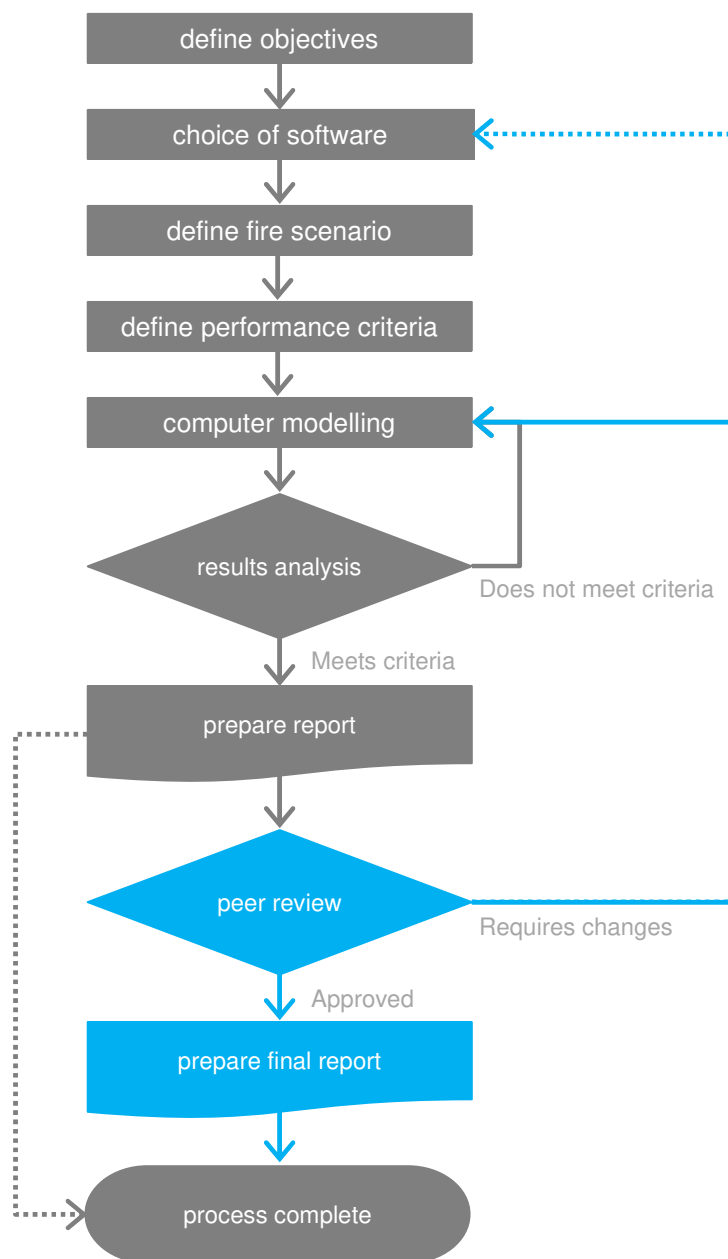
The report should be elaborated in the course of process detailing the different assumptions, decisions, results and conclusions reached. As such, the report should cover the following:

- Entity requesting the study
- Scope of study
- Name(s) of study author(s), including their specific training in the area to corroborate their technical competence to perform the required modelling
- If the study includes peer review, name(s) of reviewer(s) and information to corroborate their technical competence to review the work
- If third-party feedback (from project owner, designers, licensing bodies, insurers, installers, etc.) was obtained to perform modelling, specify these entities and their degree of involvement in the process
- Purpose of modelling
- Description of building
- Detailed description of the fire scenario, namely initial environmental conditions, location of fire and its properties, and passive and active resources that will be activated; the choice of the scenario over other possible ones needs to be properly justified
- Selected performance criteria, specifying their sources and why those criteria were chosen over others
- Software used and version
- Results in summarised form (only the most relevant ones) and analytical form (graphs comparing results with performance criteria)
- If the results did not meet the established criteria, suggest duly justified changes to the scenario or criteria
- Conclusions
- Reviewer comments (if required)
- Bibliography used as support, if applicable
- Useful attachments, such as 3D images over time and tables with more comprehensive results

The final report must be signed by the author(s) and reviewer(s).



10. peer review



10 peer review.

Depending on the complexity or purpose of the modelling, peer review might be advised. A peer here is someone who has at least the same level of technical knowledge as the person performing the modelling.

Modelling can be complex and absorbing process, bringing with it a certain risk of 'tunnel vision', i.e., of being focused only on one aspect and accidentally neglecting others. It is therefore sensible to obtain an outside view to assure a critical look at the process.

Peer review may not be required for simple modelling processes. For a more complex modelling process, peer review is desirable and could conceivably be performed by a co-worker with the necessary technical skills. However, for modelling process of greater complexity and responsibility, the reviewer should ideally belong to a third-party entity other than the modelling authors.

It is important to make a clear distinction between the role of the author and that of the reviewer. The reviewer should not outweigh the author either. The role of the reviewer is to spot errors or omissions in the process rather than opine on it. The task at hand is of a technical, rational and impartial nature. Both the author and the reviewer are members of the same (extended) team working towards a common goal by performing distinct and complementary roles.

Reviewers should be involved in the process as early as possible, allowing them to work as the modelling process evolves. The analysis should not only be limited to the report, but the reviewer should also have access to the modelling templates in order to assess their accuracy against what is intended.

The reviewer should namely validate:

- Whether the fire scenario is the most appropriate for the specified objective
- Whether the performance criteria match the objectives correctly
- Whether the modelling software chosen is the most suitable for the purpose
- Whether the model has been constructed correctly, both from a geometrical point of view and from the point of view of the implementation of the scenario in all its aspects (environmental conditions, fire, passive and active resources triggered)
- Whether the results have been properly selected and interpreted, or whether additional data is missing

The review process needs to be interactive. The reviewer should analyse the model and the report, and provide feedback, giving the author of the model the opportunity to make corrections. However, the author does not necessarily have to agree with the reviewer or vice-versa, and there may be differing opinions on the same matter. If this occurs, it should be mentioned in the final report with fairness and transparency.

11.
who can do it

11 who can do it

There are no legal provisions as to who can develop this type of modelling or its review. However, some common-sense based considerations need to be taken into account:

- The author should have solid background knowledge, in particular of thermodynamics, combustion phenomenology and fire dynamics
- The author should have sound knowledge of the selected software, preferably having received specific training
- If the study is to be attached to a Fire & Life Safety (F&LS) project, the author should ideally have the same level of professional certification as the level required for the F&LS designer

It should also be kept in mind that fire modelling may be collective work involving several experts in a variety of different roles. Thus, the considerations above should be adapted on a case-by-case basis to each expert's role in the process. Naturally, requirements will be stricter for who signs the report than for someone who has collaborated on the 3D modelling. However, for all of them, thorough knowledge within the function they are performing is required.



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13 glossary.

Smoke layer

In laminar flow, layer of hot combustion gases that accumulate in the upper part of a compartment

Smoke-free layer

In laminar flow, lower layer of the compartment where the temperature and concentration of combustion products is considerably lower than in the smoke layer

Tenability criteria

Maximum value considered to be safe to which a building occupant can be exposed during a set period of time to the effects of fire, i.e., temperature, radiant flux, toxic gases, etc.

Temperature

Physical quantity measuring the degree of molecular activity of a material compared to a reference point. The measurement unit in this document is degrees Celsius, where 0°C is the water phase change temperature from solid to liquid at a pressure of one atmosphere, and 100°C the water phase change temperature from liquid to gaseous at a pressure of one atmosphere

Heat release rate

Heat released in the form of conduction, convection and radiation.

Radiant flux

Heat flow radiating a given area, expressed in kW/m²

Zone model

Model where each compartment under study is subdivided into one or two zones calculated the energy and mass transfers across them and the compartment materials. The values calculated for each zone are average values

Finite element modelling

Model where the domain under analysis is divided into a mesh of smaller cells to calculate the energy and mass transfers across them and the compartment materials

Neutral plane

Plane in a compartment where the hydrostatic pressure matches the pressure outside the compartment

Laminar flow

Fire in which the smoke layer is clearly stratified, with a clear mostly horizontal separation between the smoke layer and the smoke-free layer

Turbulent flow

Fire in which the smoke layer is strongly turbulent, either due to high velocity air flows (for instance, jet fans), or because it is a large-scale and high-temperature fire, creating strong convection flows

Peer review

Review of process by a person or entity with at least the same technical knowledge as the author, with the aim of spotting errors or omissions

Critical temperature of a structural element

Temperature at which the collapse of the element occurs when subjected to the effects of fire; this only applies to structural elements with a uniform temperature field, such as metallic elements

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