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Proposed General Approach to Fire-Safety Scenarios

A.P. Robbins
S.M.V. Gwynne
E.D. Kuligowski

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Proposed General Approach to Fire-Safety Scenarios

A.P. Robbins
BRANZ Ltd, New Zealand

S.M.V. Gwynne
Hughes Associates, UK

E.D. Kuligowski
Fire Research Division,
Engineering Laboratory, NIST

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Preface

This report is a summary of the work performed by A.P. Robbins, S.M.V. Gwynne and E.D. Kuligowski on a standardized approach for selection of scenarios used in performance-based analysis with fire-safety in mind. This report provides a flowchart that analysts can follow to select the fire-safety scenarios to be used to assess an engineering building design performance for fire hazards. The method published in this report evolved from discussions of the draft of ISO/WD 29761 (Fire-safety engineering – Selection of design occupant behavioural scenarios and design behaviours) that was in development by Working Group 11 of ISO/TC92/SC4 during meetings in 2010. The method incorporates and builds on concepts from ISO/TS 16733 (2006), where appropriate. In preparing this report, some text from ISO/TS 16733 (2006) has been used as a starting point, with permission from the chairs of the ISO Working Group (WG6) and Sub Committee (ISO/TC92/SC4) directly responsible for the standard, and then expanded where applicable and appropriate for the purposes of this document. It is recommended that the reader of this report familiarizes themselves with ISO 16733 (2006) to provide a more comprehensive background for the context and terminology used here.

Note

This report is intended for regulators, building officials, researchers, data collectors, fire-safety engineers, designers and design analysts.

Abstract

Currently, no standardized approach exists for selection of scenarios used in performance-based analysis with all aspects of fire-safety in mind. The lack of standardized processes has the potential to lead to resulting whole building designs or parts of the same design that are either insufficient, and therefore unsafe, or overdesigned, and costly. The purpose of this report is to present a systematic approach to the identification of fire-safety scenarios for performance-based analysis of fire hazards. This consistent approach will aid analysts in identifying important fire-related scenarios that should be considered in their building design.

The focus here is on the identification of fire scenarios, since this is a critical and difficult part of the performance-based process. The number of possible fire-safety scenarios in any built environment can be very large and it is not possible to quantify them all. This large set of possibilities needs to be reduced (in an objective manner) to a manageable set of fire-safety scenarios that are amenable to analysis. A general approach to selecting fire-safety scenarios is therefore proposed. This proposed approach is applicable to the three aspects of fire-safety analyses: fire growth, spread and toxicity; human response and egress; and structural response.

The proposed approach consists of eight steps that can be briefly summarised as:

1. Defining the design problem;
2. Defining the required (one or more) fire-safety objectives, the metrics that are to be used for evaluation and the required level of performance to which the design will be evaluated;
3. Listing the full range of possible fire-safety scenarios that could be applicable to the design problem and relevant to the stated fire-safety objectives;
4. Grouping the scenarios into clusters that are similar;
5. Prioritizing the clustered scenarios for each fire-safety objective, which may result in a different priority ranking for each of the fire-safety objectives;
6. Selecting the highest priority fire-safety scenarios to be used to challenge the design;
7. Documenting the qualitative descriptions of the refined selection of fire-safety scenarios, which becomes the set of “design fire-safety scenarios”. The documentation must also include scenarios that were excluded, the reasons for omission, and the influence on the applicability of the results; and
8. Selecting the appropriate available modelling approach and quantifying the design fire-safety scenarios for input into the relevant model. The influence on the results and analysis of the assumptions and limitations associated with the model and the model input values must also be documented.

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1. INTRODUCTION

The building approval process varies among countries (Tubbs et al. 2004, ABCB 2005, Spearpoint 2008, NFPA 101 2012, Custer and Meacham 2001, SFPE 2004). Considering a simplified generic building approval process for a performance-based building design:

1. The engineering design brief is established with all of the relevant stakeholders (building owner, design team, regulatory authority, etc.) for the intended building at the start of the process. This design brief often specifies building characteristics, i.e., the intended use, functionality, occupancy, etc., as well as acceptance criteria to be used for the analysis. The design brief may also include specific features or potential hazards that the stakeholders require to be addressed in the assessment of the design (e.g. the evacuation of people with disabilities, the failure of certain fire-safety features or systems, etc.).

   Acceptance criteria may be specified by regulations in certain jurisdictions. In others, the regulatory authority involved with the approval of the final design may have guidance to specify the values for acceptance criteria. The building owner may also specify higher values for acceptance criteria than are required for acceptance by the regulatory authority. In general, acceptance criteria are associated with the building's usual operational requirements that consider expected hazards as well as unintended hazards, under which a fire event would fall. For example, fire-safety acceptance criteria in relation to a design-objective for firefighter life-safety may be of the form of the following:

   At the time first fire suppression activities begin, the conditions within the building are: a maximum radiation of AA kW/m² at BB m above the floor, a minimum height to the bottom of the smoke layer of CC m, and a maximum temperature of DD K at the ceiling. Where the values for AA, BB, CC and DD are defined by the regulations or regulatory authority, as appropriate.

2. An initial draft building design is proposed.
3. The proposed design is further developed by the design team until a final version of the design is produced that addresses all of the design objectives, including the fire-safety objectives.
4. The final version of the design is assessed. The comparison of the results of this assessment to the acceptance criteria is used as a demonstration of the appropriateness of the design.
5. The submission to the regulatory authority for consideration for building approval includes:
   - The final design.
   - The assessment method used (e.g. risk assessment, deterministic assessment, etc.).
   - The hazard challenges used in the assessments.
   - The results of the assessments of the design.

- A summary of the assessment results and uncertainty.

If a building is to be assessed for its response to fire hazards using a deterministic approach, which is the purpose of this report, the analyst is tasked with developing a set of fire-related scenarios that will test the building design. The appropriateness of the proposed building design is assessed by comparing the estimated performance of the design, when subjected to these test scenarios, to the acceptance criteria (described above). With the exception of fire-analysis related scenarios (ISO/TS 16733. 2006), currently, the analyst is left to his/her own expertise to design a method under which to identify these fire-related scenarios. This can lead to the development of interdependent sets of scenarios for the same building design, based upon different fire-safety objectives, whereas in reality these scenarios are likely to overlap across objectives. The proposed approach moves away from a 'silo' approach to one in which analysts for the same building design can acknowledge interrelationships of scenarios across specialities and, therefore, across objectives, reducing redundancy and project timelines. In addition to a varying level of expertise from both the analysts and the individuals judging these assessments, the lack of standardized processes has the potential to lead to building designs that are either insufficient, and therefore unsafe, or overdesigned, and costly.

Therefore, the objective of this report is to propose a systematic approach for selection of scenarios used in a performance-based analysis with fire-safety in mind. This report presents a step-by-step method to identify scenarios that would be used to assess the performance of a building design for fire hazard challenges. This approach is the first to combine the broad perspectives from the three fire-safety analyses (i.e., fire growth, spread and toxicity; human response and egress; and structural response) into one common methodology. It is intended that the work presented here will be used as a basis for planned future work in the development of design guides for each of the three areas of fire-safety analysis, detailing the application of the general approach and providing worked examples.

There are several limitations associated with the selection of scenarios used in a performance-based design that require the analyst's consideration. When attempting to assess the fire-safety of a building design, it is not credible to reproduce or simulate reality, nor is it credible to expect that all possible scenarios that might realistically occur will be identified. This is due to the complexity of real-world scenarios, unanticipated events, and our limited theoretical understanding of the interactions of fire events with all real world factors and the sensitivity of the outcome of any scenario to conditions which are often only crudely understood. Consequently, a model[1] (i.e. an acknowledged simplification) of reality must be used to enable a representation of the problem, so that potential solutions may be found and/or evaluated. Therefore, during every step of this approach, the analyst is reminded to document all assumptions and biases that could influence the scenarios considered and which will be eventually accepted or rejected. Additionally, the analyst needs to list all limitations and assumptions in each step of the

[1] The term 'model' is used throughout this report to represent any theoretical, analytical, empirical or computational simplification used to quantify an estimate of performance.

approach, especially in reference to the models used in the analysis. Documentation of the uncertainty of model application and results provides both the analyst and regulatory authority the context within which to interpret the building design assessment results.

1.1 Background

Other publications provide the background for the development of this approach. First, a framework for the selection of design fire scenarios for one type of fire-safety analysis (fire growth and spread) is presented in ISO/TS 16733 (2006), Fire-safety engineering -- Selection of design fire scenarios and design fires. Additional published work on the development of design fire selection frameworks is available for egress analysis by Gwynne, Kuligowski and Nilsson (2010) and for fire analysis by Wade and Robbins (Wade 2008, Robbins and Wade 2010c). Other published documents provide more of the general background that would be useful in a design fire-safety scenario selection process, such as fire incident statistics for use in estimating likelihood and consequence of possible scenarios (Apte et al. 2005, Robbins and Wade 2010a), etc. or a prescriptive approach for the design fire scenarios (e.g. Wade 2008, NFPA 101 2012, DBH 2012).

Research that has been conducted in the development of standards and guidance is not typically published; instead the final published standard represents a summary of the work that forms the basis of the standard.

1.2 Scope

This report focuses on selection of scenarios to be used in a performance-based analysis with fire-safety in mind. The approach outlined in this report covers all three aspects of fire-safety analyses, described here:

- Fire growth, fire and effluent spread, and toxicity (abbreviated to fire analysis in this document, for conciseness),
- Human response and egress (abbreviated to egress analysis, for conciseness), and
- Structural response (abbreviated to structural analysis, for conciseness).

This report provides a flowchart that analysts can follow to select the fire-safety scenarios that will be used to assess the performance of an engineering building design for fire hazard challenges. This report builds on previously published work, broadening the scope to include a wider range of types of fire-safety analysis to produce a common approach. The snapshot that this report provides is intended as a reference for further collaborative discussions and development of design guides for specific types of analysis and worked examples.

2. DEFINITIONS

The following are the definitions for the terminology introduced in this document, as well as terminology used in this document that is defined elsewhere (ISO13943 2008; ISO/TS16733 2006).

‘Acceptance criteria’ is the level (i.e., the quantitative description of performance) to which the building design must achieve the stated objectives.

‘Assessment’ is the testing of a building design for one or a combination of design objectives that may utilize one or more types of analysis (i.e., fire, egress or structural analysis).

‘Clustering’ is an approach used to reduce the number of scenarios for analysis based upon similarities among scenarios. This term is also used in ISO/TS16733 (2006).

‘Design fire-safety scenario’ is a fire-safety scenario (see definition below) that has been chosen for use in the fire-safety analysis of the building design. The set of design scenarios contains the set of fire-safety scenarios (see definition above) that have been prioritised from a comprehensive set of possible scenarios based on the defined problem characteristics and objective(s) to challenge the engineering design for the fire-safety analysis. This definition is based upon the ISO/TS16733 (2006) definition for a “design fire scenario” and broadened to include other fire-safety objectives.

‘Fire-safety design objective’ is a requirement (i.e., a qualitative description of performance) that the building design must achieve and may include life-safety, property protection, continuity of operations, environmental protection, heritage protection, structural performance, etc.

‘Fire-safety scenario’ is a description of key factors related to the event initiation and evolution of these factors as they impact defined fire-safety objective(s) (including but not limited to life safety, property protection, continuity of operations, environmental protection, and structural performance). The definition for fire-safety scenario is broader than the ISO definition of a ‘fire scenario’ [ISO/TS16733 2006] because the above definition accounts for fire-safety objectives that may not be solely related to the analysis of fire and effluent development and spread.

‘Key model factors’ are the parameters that most appropriately represent the ‘real-world factors’ after translation into a model framework. This framework facilitates the assessment of the design problem, while considering the limitations of the possible modelling approaches and available parameter values.

‘Real-world factors’ are the observable and quantifiable characteristics that influence the outcome of a real-world fire event.

‘Types of analysis’ in this report refers to approaches used to test the building design from the technical perspectives of either fire growth, spread and toxicity; human response and egress; or structural response.

3. OVERVIEW OF THE IDENTIFICATION OF FIRE-SAFETY SCENARIOS

The general approach proposed here is intended to be applied to a design problem across a variety of fire-safety design objective(s):

- Life safety,
- Property protection,
- Continuity of operations,
- Environmental protection,
- Structural performance,
- Heritage protection, or
- Other fire-safety design objectives.

Assessment of the building design for each of the fire-safety design objectives may require results from either a single type of analysis or a combined analysis approach. Incorporating results from a fire analysis, egress analysis and/or structural analysis may provide a more holistic assessment of the modelled scenario. Furthermore, the analyst may wish to focus on one or multiple fire-safety-design objectives within the same building design analysis. The proposed scenario selection approach provides benefits for projects involving multiple objectives and analysts, because factors relevant to one type of analysis may be dependent on or interactive with factors that would typically be associated with a different type of analysis. Also, applying a consistent approach for all analysis perspectives enables easier identification of relevant interrelationships of factors for any single design objective. For example, route choice in an egress analysis may depend on the local environmental or structural conditions within the building during a fire and, in turn, the opening and closing of doors in an egress analysis may influence the smoke movement in a fire analysis.

Since the scenario selection approach is all-inclusive of various types of design analyses, unnecessary replication of analysis effort is reduced when analysts are tasked with multiple objectives for a single design problem. The use of a common template for different analyses may also emphasize the linkage between different areas of fire-safety analysis, using common language for the description of the tasks involved in fire-safety scenario selection. This is valuable when a single objective requires multiple types of analyses to complete an assessment, and when the building design team consists of analysts with different expertise in the areas of fire-safety analysis.

Independent of the type of analysis perspective, the design fire-safety scenarios need to be appropriate to the design problem and the stated objectives of the fire-safety engineering task. The proposed approach encourages the identification of fire-safety scenarios through the careful consideration of associated real-world and key model factors with all aspects of fire-safety in mind. Key aspects of the scenario selection process, explained in the detailed steps below, are:

- Prepare the fire-safety assessment requirements:
    - define the design problem to be analysed (Task A);
    - define the required analysis, design objectives and acceptance criteria (Task B);
- Identify a comprehensive set of possible fire-safety scenarios based on key model factors (Task C):
    - consider assumptions and limitations for the translation of real-world scenarios and factors into model scenarios and factors;
- Refine model scenarios:
    - cluster similar possible fire-safety scenarios (Task D);
    - prioritize the clustered set of fire-safety scenarios (Task E);
    - select the fire-safety scenarios to be used as design fire-safety scenarios (Task F) based on the results from the clustering and prioritization;
    - document the final set of design fire-safety scenarios, including assumptions and limitations from the viewpoints of each of the individual scenarios as well as of the comprehensiveness of the suite of scenarios (Task G).

The seven steps outlined below provide a systematic approach towards identifying appropriate, credible and applicable design fire-safety scenarios.

A schematic of the proposed general approach is included in Figure 1.

General Approach to Identifying Fire-Safety Scenarios

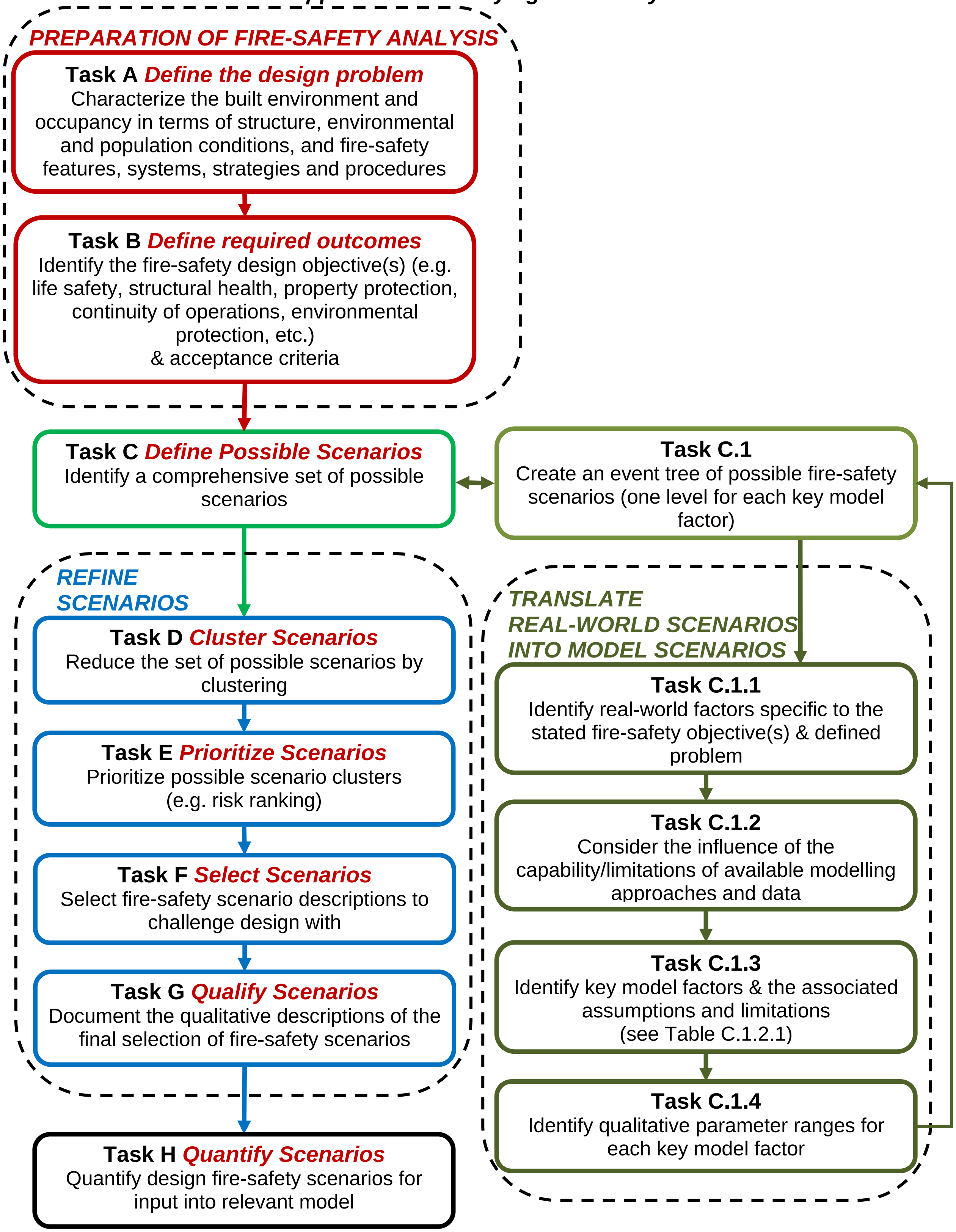

Figure 1: Schematic of a general approach to identify fire-safety scenarios

4. STEPS FOR IDENTIFYING A SET OF DESIGN FIRE-SAFETY SCENARIOS

In this section, the proposed approach is described in detail, organized by the tasks shown in Figure 1. These tasks represent the key stages to identify design fire-safety scenarios in a performance-based analysis.

4.1 Task A: Define the design problem

The scope of the intended design problem and a proposed engineering design solution are defined in this task. The analyst should fully define the design problem in terms of both the built environment and the occupancy. The definition of the design problem may include, but is not limited to, the following:

- Internal and external geometry of the structure,
- Population characteristics,
- General environmental conditions,
- Functionality and usage of the building,
- Structural specifications and loadings, and
- Active and passive fire-safety features, systems, strategies and procedures.

The fire-safety features, systems, strategies and procedures incorporated into the initial design relies on the expertise and skill of the analyst(s) to anticipate suitable solutions for the draft building design, such that the overall analysis subsequently carried out is relatively efficient and economic.

4.2 Task B: Define required objectives

In Task B, the analyst should identify the fire-safety design objective(s) and associated acceptance criteria. As stated earlier, the fire-safety design objectives may be one or more of the following:

- Life safety,
- Property protection,
- Continuity of operations,
- Environmental protection,
- Structural performance,
- Heritage protection, or
- Other fire-safety design objectives.

A fire-safety design objective is a qualitative description of performance that the building design must achieve. A fire-safety objective related to a particular building design directly influences the types of fire-safety scenarios used to test the design. As stated earlier, an analyst may identify multiple objectives for the same design. When there are multiple design objectives that cannot be combined into a single assessment, several building design assessments may need to be performed. Also, it may take several iterations of the design (e.g. layout of internal spaces, fire-safety features, systems, procedures, etc. that may need to be negotiated with stakeholders) to achieve all the fire-safety design objectives to, at least, the level defined by the acceptance criteria.

For each design objective, the analyst must also identify the associated acceptance criteria. Each set of acceptance criteria will be used as the threshold to judge the appropriateness of the design, as defined in Task A, for each fire-safety design objective. The acceptance criteria may be defined by codes, standards, guidance documents or negotiated by stakeholders with the regulatory authority at the beginning of the project, and documented in the engineering design brief. Acceptance criteria may comprise functional requirements and/or performance criteria. The metrics associated with the acceptance criteria will inform the appropriate selection of key model factors.

4.3 Task C: Define possible fire-safety scenarios

The purpose of Task C is to identify a comprehensive set of possible fire-safety scenarios that are relevant to the defined design objectives of the assessment (defined in Task B). Task C contains a series of steps to guide the analyst in the identification of these scenarios using an event tree analysis, whereby analysts translate real-world factors and scenarios into model factors and scenarios. A refined set of these modelling scenarios is ultimately used to challenge the design. The steps in this task closely resemble other example approaches (Kuligowski and Gwynne 2005, Gwynne, Kuligowski and Nilsson 2012). New to these approaches is the suggestion of Task C.1: the use of event trees to visualize the combinations of possible real-world factors to produce real-world scenarios.

Note: The limitations of the model scenarios to account for real-world scenarios must be taken into account during this task.

4.3.1 Task C.1: Create an event tree

One way to develop real-world scenarios is the use of an event tree. If an event tree approach (Grimvall et al. 2010, Stamatelatos and Dezfuli 2011) is chosen for use in this task, the analyst should construct an event tree that represents alternative event sequences from fire ignition to outcome related to the defined design problem and stated fire-safety objective(s).

Event trees are constructed by starting with an initial event, such as an ignition, in combination with initial states for all relevant building and fire-safety systems/features and occupants. A fork is constructed and branches added to reflect each possible successive event. This process is repeated until all possible initial states have been represented. Each fork is constructed on the basis of occurrence of the preceding event. For example, considering a detection event of a fire after ignition, it may be detected by an occupant, an automatic detector, or not detected, whereby each of these events would be represented by a separate branch that would lead to different events. Each path through this tree from fire ignition to outcome represents a fire-safety scenario for consideration. Examples of the construction of an event tree are given for fire analysis in ISO/TS16733 (2006).

Alternatively, a fault tree (Sinnamon and Andrews 1997, IEC 61025 2006, Grimvall et al. 2010, Stamatelatos and Dezfuli 2011) can be constructed. Fault trees are logic trees (like event trees), but ones in which each branch is based on a condition or state, rather than an event in time. For example, considering an automatic detection system is present, the state may be operable (working and would be expected to operate in the conditions), not operable (working but the fire conditions, location, etc. would not be expected to activate the system), or disabled (will not activate, no matter the fire conditions), whereby each of these states would be represented as a separate branch of a fault tree. Fault trees can be beneficial when there are likely to be a number of factors each with multiple possibilities for initial states.

As a way to differentiate between methods:

- Event tree: the characteristics of the intended building occupants may be described in terms of times of the day or types of potential events for which the building is designed, e.g.:
    - day-time,
    - night-time,
    - during a special-event,
    - during preparation or clean-up of an event,
    - during filling of a crowd area (i.e. pre-performance), etc.; or
- Fault tree: the characteristics of the intended building occupants may be described in terms of use or event states, e.g.:
    - conscious state: awake, asleep or intoxicated,
    - self-rescue state: capable of self-rescue, potential need for assisted-rescue or unable to self-rescue,
    - state of familiarity with building: highly familiar, moderate, no familiarity, etc.

An initial fault tree could be used to set up the alternative initial states and a commonly formatted event tree then appended to each end-point of the fault tree, corresponding to a full specification of initial conditions. A scenario will then be a single path through this hybrid tree.

Creating a tree that provides a comprehensive set of fire-safety scenarios including the assumptions and limitations associated with the translation between real-world and model factors may be an iterative process, as indicated by the components for the flowchart schematic (Figure 1) for Task C.1.

4.3.1.1 Task C.1.1: Identify real-world factors

In order to develop the event tree, the analyst should identify real-world factors specific to the defined design problem and stated fire-safety objective(s). Real-world scenarios and factors are complex and difficult to quantify. With each of the fire-safety design objectives in mind, a combination of the following sources could be employed to capture the range of possible common occurrence and high consequence real-world scenarios, and the associated factors:

- Relevant fire-incident statistics (incidents, injuries, fatalities, property loss, area of flame damage etc.);
- Engineering judgement of the specific characteristics of the built environment, intended occupancies, intended space usage, possible presence of potential ignition sources, fuel packages, etc.;
- Evacuation drills;
- Exploratory pre-screening modelling; and
- Relevant test data, when available.
- Another approach that the analyst might utilise to assist in identifying real-world factors is to systematically move through the design, considering each of the physical spaces in the context of their intended use, and what real-world scenarios would be possible to identify the key factors involved. This approach may be supplemented with additional information from the listed sources above. In addition, the analyst might consider the fire-safety scenarios that could arise from the potential fire hazards identified during the qualitative design review phase as associated with the intended use of the property or the design. Other critical high consequence scenarios might also be identified for consideration.

The analyst might also include consideration of possible scenarios, when failure or partial failure may occur of fire-safety features, systems, strategies and procedures, or the sub-optimal actions of people may occur, e.g. poorly trained staff or casual visitors. Any of these effects could introduce new potential fire-safety factors and scenarios.

A non-exhaustive list of examples of real-world factors that may be considered during a fire-safety analysis may include, but is not limited to:

- Issues related to the specific design problem being considered:
    - Building layout;
    - Building construction and materials;
    - changes of the building materials, components, etc. over time according to operational wear, maintenance, vandalism, etc.;
    - Distributions of characteristics of intended building occupancies and changes with each variation of building functionality and usage;
    - Changes of the distributions of characteristics of intended population over time;
    - Surveyed opinions of building occupants;

  - Intended building functionality and/or usage(s) and changes with different seasons, etc.;
  - Potential adverse environmental conditions (e.g. high winds, post-earthquake, etc.)
  - Potential people interaction with fire start;
  - Potential ignition sources;
  - Potential first material ignited;
  - Potential equipment involved in ignition;
  - Fire development and spread throughout compartment and building;
  - Fire effluent spread throughout building; and
- Issues and lessons from similar situations, design aspects and building operation learned from historical fire incident records and testing in terms of:
  - Estimated outcomes of casualties, fire losses, average area of structure lost to fire damage, etc.;
  - Estimated reliability and effectiveness of active and passive fire-safety features, systems, strategies and procedures, etc.;
  - Influence of codes and regulations used for building stock that make up the historic records, compared to the current codes and regulations;
  - Influence of differences of actual building functionality and usage on applicability of historic records; and
  - Influence of changes in population on applicability of historic records.

Real-world factors can also include unforseen changes in usage and occupant culture that occur during the lifetime of a building, which may not be included in a model scenario due to modelling and data limitations. Such limitations must be included in the documentation and interpretation of the modelling results.

As mentioned earlier, this approach applies to various types of fire-safety objectives. Some factors may be irrelevant to a particular assessment, depending on the defined design problem and fire-safety objectives. The analyst must record these considerations and the reasons why the factor has not been included in the analysis. However, there may be factors that overlap in some way; i.e., factors needed as input to one type of analysis may be the outcomes of other analyses. For example, an assessment of a building design for the design objective of life-safety may need both fire and egress analyses to model the design scenarios. Whereby conditions throughout the building during a fire event, estimated in a fire analysis, may be used to provide values for some factors for the egress analysis.

4.3.1.2 Task C.1.2: Consider available model capability and limitations

The modelling tools available to the analyst, including hand calculations and computerized techniques, are limited in their scope and capabilities. However, these modelling tools are often the best practical solution for performance-based analyses. As mentioned earlier, models are essentially a crude estimate of reality. Therefore, it is important to highlight model capabilities and limitations, and how these short-falls may be compensated for or may impact the applicability of the modelling results. Once the analyst is aware of the types of situations a model can and cannot simulate, he/she will be better equipped to translate real-world factors into modelling input (tasks described later in this approach) and to interpret the model results. The capabilities and limitations of the available models must be acknowledged, evaluated, addressed to reduce the impact of these limitations, documented as an integral part of the design assessment, and ultimately included in the interpretation of the modelling results.

In addition to model limitations, the available relevant data sets to simulate real-world scenarios may also be limited. These limitations must be taken into account early to minimize unnecessary re-iterations of the scenario selection process and to understand the influence of these limitations in the selection of the scenarios, and subsequently on the assessment results. How this uncertainty is incorporated into the building design by the analyst must be clearly documented.

4.3.1.3 Task C.1.3: Identify key model factors

In Task C.1.3, real-world scenarios and factors (Task C.1.1) are simplified to model scenarios and model factors (as shown in the schematic presented in Figure 2). These factors essentially represent the inputs for the modelling tools.

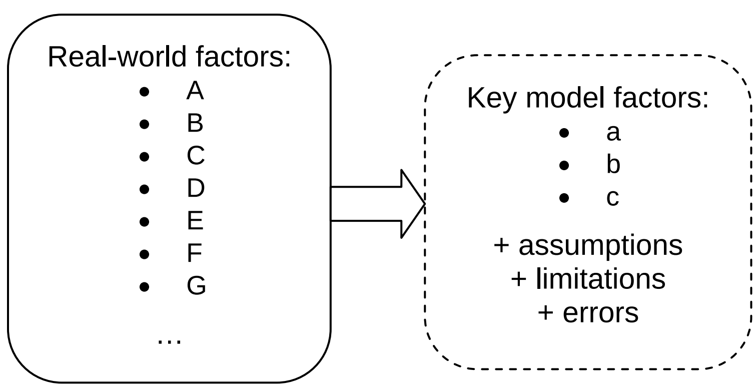

Figure 2: Schematic of the general relationship between real-world scenarios and factors (Task C.1.1), and model scenarios and key factors with associated limitations, assumptions and errors (Task C.1.2)

As shown in Figure 2, the analyst will likely be required to develop a smaller set of model factors than real-world factors. First, not all modelling approaches/tools can simulate all real-world factors, based upon the modelling capabilities and limitations. Additionally, there may be limited data (or a lack of data altogether) for some of the real-world factors identified in Task C.1.1. Finally, some model factors can be combined into a single model input based on similarities in the data used to develop the input. The analyst must record:

- Model factors that cannot be included because of limitations of available modelling approaches or relevant data,
- The reasons why the model factor has not been included in the analysis, and
- The subsequent influence on the applicability of the resulting analysis.

It should also be noted that some model inputs may be based on model outputs from other type of analysis. For instance, as mentioned previously, conditions within the building during a fire, as calculated during a fire analysis, may be used in an egress analysis. This provides yet another example of the benefits of this approach to select scenarios to be used in a performance-based design that incorporates multiple types of objectives, types of analyses and/or a team of multiple expert analysts.

A non-exhaustive list of examples of key model factors related to egress, fire and structural modelling are included in Table 1. In Table 1, model factors that are considered in relative isolation within one type of analysis are indicated with an 'O'. Model factors that are needed to be considered for the analysis, but are calculated during, or influenced by, another type of analysis are indicated with an 'X'. For example, in the case of a model factor associated with "Status of Exit Routes" (in Fire & Smoke Development & Spread section of Table 1), both the egress and fire analyses could provide information to each other. A fire analysis could provide local fire conditions that influence the availability of certain exits within an egress analysis. An egress analysis could provide information on operations of doors that influence local conditions within a fire analysis.

In some cases, the selection of the modelling tool(s) may limit the ability to simulate these types of interactions, because of in-built model assumptions and limitations of inputs and outputs of the particular models. For example, in the case of "Human Response" model factors, some modelling approaches account for all or combinations of these factors, whereas other approaches may be limited to a model input that may be a single value (where a distribution may be more appropriate) or a default value in the model (where it may not be controlled by the model user at all). The influence on the model results of whether and how the factors are able to be included in the analysis approach may need to be considered carefully.

Table 1 shows the interactions and potential interactions between model factors for different types of fire-safety analyses, namely fire, egress and structural analysis.

Table 1: Example model factors for consideration during egress, fire and/or structural analyses

Description of Model Factor for Consideration	Egress	Fire	Structure
Building Layout	O	O	O
Non-Emergency Environmental Conditions	O	O	
Fire Start			
Potential Fire Hazards/Ignition Sources		O	O
Location of Ignition	O	O	O
Relative Time of Day for Event Start	O	O	O
Population			
Size	O	X	
Location	O	X	
Characteristics / Distribution	O	X	
Impairments	O		
Activities/Status	O	X	
Commitment/Engagement/Habituation	O		
Language/Cultural	O		
Social Role/Affiliation	O		
Familiarity	O		
Training/Experience	O		
Visual Access	X	O	
Fire & Smoke Development & Spread			
Type of Fire		O	O
Distribution and Types of Fuels/Fire Load Density		O	O
Internal Ventilation Conditions		O	O
External Environmental Conditions		O	O
Fire Size/Growth		O	O
Criteria for Fire Spread			O
Status of Exit Routes, incl. opening/closing doors	X	X	
Building Structure			
Structural Members		O	O
Structural Loads			O
Characteristics of Elements and Connections			O
Restraint Conditions			O
Thermal & Mechanical Material Properties			O
Fire-safety systems, features, strategies, and procedures			
Technical – Detection	O	O	
Human – Detection	O	O	
Technical – Notification	O	O	
Human – Notification	O		
Human – Evacuation Procedure/ Strategy	O	O	
Technical – Compartmentation		O	O
Technical – Suppression Systems	O	O	O
Human – Suppression, incl. Fire Fighting	O	O	O
Human Response			
Pre-Evacuation	X		
Assumed Travel Speeds	X		
Attainable Speeds	X		
Route Use	X	X	
Flow Constraints	X		

Table 1 Notes:
O – Factor that is needed to be considered for the analysis indicated in the column header.
X – Factor that is needed to be considered for the analysis, but the factor is calculated during, or influenced by, another type of analysis or the selection of modelling approach.

Task C.1.3 requires that the analyst document the limitations, assumptions and errors in addition to the list of modelling factors. Any time an analyst moves from real-world to modelling factors, a level of uncertainty of the modelling results is introduced. This uncertainty is a consequence of the assumptions and estimates that are used in the model calculations, and the limits of the application of the model results. Assumptions may include in-built-model safety factors, other safety factors applied by the analyst, and so on. Limitations may include the capabilities of available models, applicability of available data sets to estimate model inputs, and so on. Errors include the effect of the assumptions and limitations of the approach and available data and may also include unintended compounding of assumptions, poor estimation of model input parameters, and so on. The assumptions, limitations and errors of the analysis approach and implementation must be accounted for in the building design to provide a complete assessment of the design.

4.3.1.4 Task C.1.4: Identify qualitative ranges

The analyst should identify qualitative parameter ranges or statuses for each key model factor. Qualifying the key modelling factors may help the analyst to refine the scenarios (made up by the modelling factors) in upcoming tasks. A non-exhaustive list of some examples of qualified ranges, for model factors previously discussed, is included in Table 2.

Table 2: Examples of model parameter qualitative ranges, values or statuses. (Note that this is not an exhaustive list.)

Description of Model Factor for Consideration	Examples of Qualitative Ranges
Building Layout	• Identify the internal and external spaces • Identify locations of functionality and usage • Identify exit routes o including, but not limited to, lifts/elevators and stairwell design
Non-Emergency Environmental Conditions	• Describe range of expected environmental conditions
Fire Start	
Potential Fire Hazards/Ignition Sources	• Descriptive values for intended functionality, contents and usage of the spaces in relation to potential fire starts
Location of Ignition	• Descriptive value of the internal or external space
Relative Time of Day for Event Start	• Descriptive values: o During peak/off-peak usage, during/out-side-of business hours, during/in-between/after a regular/one-off function, etc.
Population	
Size	• Descriptive value: Small, medium, large, crowd, skeleton crew, etc.
Location	• Space in building layout • Assignments to rooms within the building
Characteristics / Distribution	• Age: Children, adolescents, adults, elderly • Gender: Male/female • Fitness: BMI, etc.
Impairments	• Physical: o Able-bodied to disabled (wheel-chair movement) to non-ambulatory • Hearing: o None, partial, deafness • Visual: o None, partial, blindness • Cognitive: o None, partial, cognitive impairments requiring full-time care • Temporal applicability of impairment: o Temporary (expected to heal fully in the short-term) to permanent • Sensitivity to local fire and fire effluent conditions: o Average sensitivities to hyper-sensitivities
Activities/Status	• Commitment to activity o None, low, medium, high • Status: o Awake, drowsy, asleep o Intoxication: None, minor, medium, major
Commitment/ Engagement/ Habituation	• Working/living in the building for a long time, short period of time (need to define), visitor of the building
Language/Cultural	• English language, other language
Social Role/Affiliation	• Loose, medium, strong
Familiarity	• With others, see affiliation • With building: None, low, medium, high

Table 2 (continued): Examples of model parameter qualitative ranges, values or statuses. (Note that this is not an exhaustive list.)

Description of Model Factor for Consideration	Examples of Qualitative Ranges
Population (continued)	
Training/Experience	• None, low, medium, high
Visual Access	• None, low, medium, high
Fire & Smoke Development & Spread	
Type of Fire	• Range: flaming or smouldering
Distribution and Types of Fuels/Fire Load Density	• Contents and furnishings o Initial status: as new or degraded by age or vandalism, distribution o Initial distribution: uniform, stacked, etc. • Interior and exterior finishing o Initial status: as new or degraded by age or vandalism or compromised • Materials control o Status: as new or degraded by age or vandalism
Internal Ventilation Conditions	• Status: o Under-ventilated, fully ventilated
External Environmental Conditions	• Descriptive range of expected environmental conditions
Fire Size	• Growth rate: o Slow, moderate, fast, ultra-fast • Range: o Whether secondary items ignited by fire, etc.
Criteria for Fire Spread	• Spread rate: none, slow, moderate, fast, etc.
Status of Exit Routes, incl. opening/closing doors	• Blocked exit routes, • Which exit routes are used and how heavily, etc.
Building Structure	
Structural Members	• Initial status: as designed or compromised
Structural Loads (e.g. live, dead, wind loads, etc.)	• Range: low, medium, high
Characteristics of Elements and Connections	• Elements: Column, beam, slab, shell, etc. • Connections: Fixed, free, etc.
Restraint Conditions	• Fixed, free, etc.
Thermal & Mechanical Material Properties	• Ranges: low, medium, high thermal and mechanical susceptibility

Table 2 (continued): Examples of model parameter qualitative ranges, values or statuses. (Note that this is not an exhaustive list.)

Description of Model Factor for Consideration	Examples of Qualitative Ranges
Fire-safety systems, features, strategies, and procedures	
Technical – General	• initial status: present, not present • performance: performs as designed or with a reduced quality or degree of performance • reliability: poor, moderate, high
Technical – Detection	• (See examples for 'Technical – General' above)
Human – Detection	• Time to detection: short, medium, long
Technical – Notification	• Information level for occupants: insufficient, or sufficient information • (See examples for 'Technical – General' above)
Human – Notification	• Information level for occupants: insufficient, or sufficient information
Human – Evacuation Procedure/ Strategy	• (See examples for 'Technical – General' above)
Technical – Compartmentation	• (See examples for 'Technical – General' above) • Compartment size range: small, medium, large • Initial status: as designed or compromised by penetrations or in other ways • Example – openings: o Initial status: as new or degraded, status o Status at start and during fire: open or closed • Example – walls/ceiling/floor assemblies:
Technical – Suppression Systems	• (See examples for 'Technical – General' above)
Human – Suppression, incl. Fire Fighting	• Occupant efforts: o Response time o Intervention time o Effectiveness of operations • Fire fighter operations: o Response time o Intervention time o Effectiveness of operations
Human Response	
Human Response Factors – in general	• Incorporated in possible modelling approach, only available as a single value model input or incorporated indirectly in a model input
Pre-Evacuation	• Times: range • Behaviours include: information seeking, preparation, helping others (including warning others), and evacuating
Assumed Travel Speeds	• Single values, or distributions • Range: unimpaired, impaired
Attainable Speeds	• Range: low, moderate, high
Route Use	• Descriptive value: One familiar route, nearest, etc.
Flow Constraints	• Range: low, moderate, high

4.4 Refine Scenarios

As a result of Task C (previously presented), the analyst has developed a comprehensive set of possible scenarios (made up of modelling factors). The next set of tasks allows the analyst to refine the modelling scenarios developed in Task C and develop a set of design fire-safety scenarios; i.e., those scenarios that will actually be modelled and included as part of the performance-based assessment of the building design. This next section describes a series of four tasks that describes how to cluster, prioritize, select, and document the final set of fire-safety scenarios, also known as the design fire-safety scenarios.

4.4.1 Task D: Cluster scenarios

The first step, labelled as Task D, prompts the analyst to reduce the number of possible scenarios by clustering. A description of clustering is included in ISO 16733 (2006) and essentially means that the analyst begins to group similar scenarios together, reducing redundancy among modelling input scenarios. Clustering is achieved by examining each scenario to determine if equivalent model scenarios are being considered (e.g., in terms of building usage, occupant characteristics and events at the start of and during a fire). Then, even though the real-world scenarios being represented are different, scenarios can be combined such that the net effect of the combined impact of the factors is equivalent. This will enable scenario-equivalent clusters to be formed, with each cluster being represented by a single model scenario. The influence on the applicability of the assessment results by the loss of detail due to clustering of scenarios must be carefully considered by the analyst in terms.

4.4.2 Task E: Prioritize scenarios

The analyst should prioritize the scenario clusters. A prioritization process, such as risk ranking (Kaiser 1980, Watts 1991, NFPA 101M 1987, Grimvall et al. 2010), provides a helpful basis for the ultimate selection of design fire-safety scenarios (upcoming Task F). A process, such as risk ranking, takes into account the likelihood of occurrence and a measure of the consequences of the scenario (if the scenario was to occur). The uncertainty of the likelihood and consequences must also be taken into account (e.g. Robbins and Wade (2010b)).

Where values are available for the consequence and likelihood of each scenario, risk assessment techniques, such as the full risk assessment described in ISO 16732 (2006), may be applied to the selection of design fire-safety scenarios. Where insufficient information is available to provide these values for each cluster of scenarios, engineering judgement, considering the uncertainty, must be applied in order to methodically prioritize the scenario clusters.

In a building assessment, where more than one fire-safety objective is defined, each objective may be associated with a different priority ranking of the clustered scenarios.

4.4.3 Task F: Select scenarios

For each fire-safety objective, the analyst should select the highest priority fire-safety scenarios to be used to challenge the design. Input from the stakeholders into this selection process is recommended.

If a risk assessment approach is used, the selected scenarios should represent a major portion of the cumulative risk (i.e., sum of the risk of all scenarios). The reasons for not selecting the scenarios and the subsequent influence of these omissions on the interpretation of the assessment results must be documented.

- In making final selections, the influence of certain common errors or biases needs to be considered. The following is a list of important considerations for the analyst when selecting scenarios:
- If multiple high-consequence, low-probability scenarios are eliminated from consideration, it is essential to ensure that the eliminated scenarios do not have a moderate or high collective probability. When possible, it is better to combine like scenarios, so that more scenarios are directly represented and analysed, than to eliminate scenarios.
- It is inappropriate to eliminate a scenario, despite its substantial contribution to risk, because it makes a particular fire-safety system, feature, or design choice appear attractive or unattractive.
- It is inappropriate at this stage to eliminate a scenario, despite its substantial contribution to risk, because the only design choices capable of producing an acceptable outcome for that scenario are very expensive. A decision to accept the risk of a particular scenario because of the high cost of eliminating or reducing that risk should be made after more detailed analysis and only with the full involvement of the stakeholders.
- It can be appropriate to eliminate a scenario, despite its substantial contribution to risk, if no identifiable design choice can reduce or eliminate that risk. Risks to persons who are intimate with the starting point of a fire or who are temporarily incapable of acts of self-preservation (e.g., because of consumption of alcohol, illicit drugs, or medication, where this is not an expected characteristic of the intended occupancy) may be examples of the bases for scenarios that can legitimately be eliminated at this stage. Identification of any such scenarios eliminated and the reasons for elimination must be documented by the analyst.

4.4.4 Task G: Qualify scenarios

In Task G, the analyst must document, in detail, the final set of fire-safety scenarios for the building assessment. This final selection of fire-safety scenarios becomes the set of “design fire-safety scenarios”, when they are quantified. The documentation is to include the following:

- Descriptions of the fire-safety scenarios used for analysis,

- Descriptions of the fire-safety scenarios not selected for analysis and reasons for these omissions,
- The assumptions of the analyst and the modelling tool(s),
- The limitations of the data used in the assessment and the modelling tool(s),
- The applicability of the modelling results based upon these assumptions, limitations, and omissions.

4.5 Task H: Quantify scenarios

The analyst needs to select the appropriate available modelling approach and quantify the design fire-safety scenarios for input into the relevant models. In this task, the analyst must provide data and/or chosen values for the modelling factors that serve as input for the chosen model(s). The assumptions and limitations associated with the values chosen for the key model factors must be included in the documentation. The entire process from the development of real-world factors to the quantification of the design scenarios and identification of the modelling approach is shown in Figure 3.

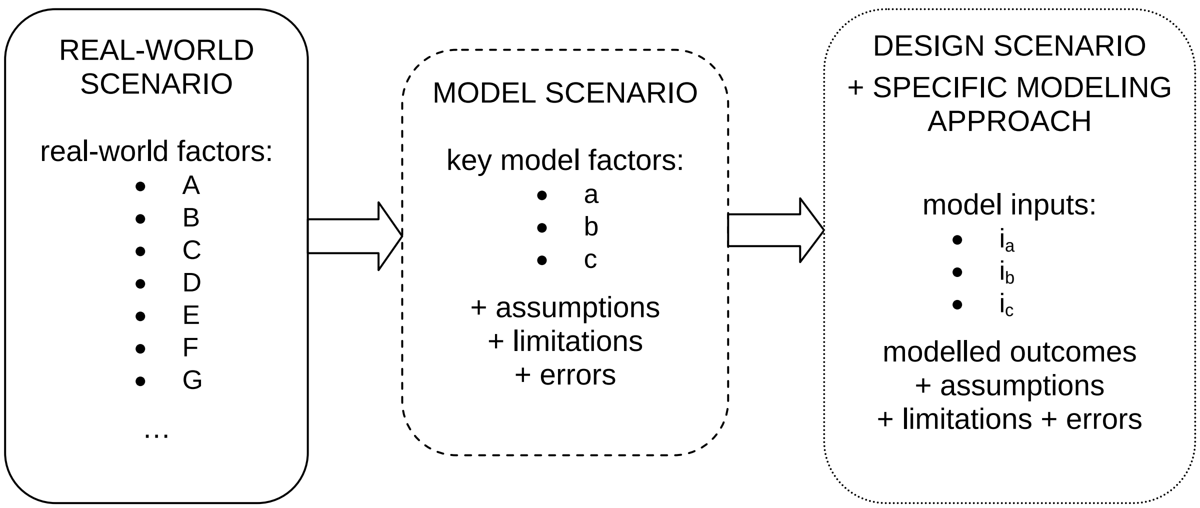

Figure 3: Schematic of the general relationship between real-world scenarios and factors (Task C.1.1), model scenarios and key factors with associated limitations, assumptions and errors (Task C1.2), and the design fire-safety scenarios with associated modelled outcomes, assumptions, limitations and errors (Task H).

Finding appropriate data for key model factors may be a significant limitation in this process. The implications of these limitations must also be incorporated into the analysis of modelled outcomes and incorporated into the design of the building. If this approach is followed in order, the analyst will have already identified limitations associated with the model approaches and the data available in Task C1.2. Values to be used in the quantification of scenarios are dependent on the defined problem, objectives and modelling approach and are not discussed here.

4.6 Iterative nature of the general scenario selection approach

The general approach outlined in this report is iterative in nature. The analyst may be required to repeat certain tasks based upon changes made to the design, design objectives, or acceptance criteria over the project timeline. For example, the designer(s) may change the design at any stage, including design changes made to achieve one or more of the performance criteria. In every case, the scenario selection must be restarted from Task A, to capture the changes to the design and ensure that the influences of the changes are included in the consideration of scenarios for selection for each design objective.

5. SUMMARY

A general approach to selecting qualified design fire-safety scenarios has been outlined. This is a single framework, where the details can be tailored to the fire-safety objectives and type of analyses. Therefore, this approach can be used by different analysts to identify scenarios that address key aspects of fire-safety of fire, egress and structural analyses in the context of the defined design problem and fire-safety objective(s).

The number of real-world scenarios in any built environment can be very large and it is not possible to quantify them all in a fire-safety analysis. The approach described here may be used to produce an initial set of possible fire-safety scenarios that combine real-world considerations with modelling and data limitations. This large set of possibilities can be reduced to a representative set of fire-safety scenarios that are amenable to analysis.

Uncertainties (limitations, assumptions and errors) that need to be documented and the influence included in the interpretation of modelling results and the consequent assessment of the building design include:

- Limitations of translation of real-world scenarios into model scenarios,
- Loss of detail by clustering of scenarios,
- The uncertainty associated with the priority allocated by the analyst to each of the clusters of scenarios,
- Model factors that cannot be included because of limitations of available modelling approaches or relevant data,
- Applicability of available data sets to estimate model inputs and poor estimation of model input parameters,
- Assumptions, limitations and errors of the analysis approach and implementation, and
- Potential unintended compounding of in-built model assumptions and/or assumptions made by the analyst.

Beyond documentation of the uncertainties, they need to be carefully considered in the analysis to ensure safety over the lifetime of the building. Examples of the quantification of the design fire-safety scenarios are specific to the design problem. Examples of such specification will be available with the development of worked examples, which are currently underway for a range of design problems.

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