Fire Safety Engineering

The Methods Report

THE WARREN CENTRE

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THE WARREN CENTRE

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FIRE SAFETY ENGINEERING PROJECT

This is the second research project of The Warren Centre at the University of Sydney relating to Fire Safety Engineering. The first project in 1989 paved the way for the creation of the Fire Code Reform Centre to co-ordinate fire research nationally in 1994 and gave major impetus to the development of the performance-based Building Code of Australia, published in 1996. This current Warren Centre Project on fire safety engineering will address many of the major challenges facing governments, regulatory authorities and practitioners in relation to fire safety engineering and community safety in buildings.

This is the third report issued in this current series. The report *Current Status of Education, Training and Stated Competencies*, the "Education Report", issued in January 2019.

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Executive Summary

THIS IS THE REPORT INTO TASK 2.1.1 OF THE WARREN CENTRE PROJECT INTO FIRE SAFETY ENGINEERING. THE REPORT DISCUSSES THE UTILITY AND BENEFIT OF THE INTERNATIONAL FIRE SAFETY ENGINEERING GUIDELINES (IFEG), FIRE SAFETY VERIFICATION METHODS (FSVM), AND PRACTICE GUIDES ISSUED BY VARIOUS PROFESSIONAL BODIES.

The role of all of these supporting materials in fire safety engineering design, analysis and assessment of adequacy is discussed. Shortcomings or other risks associated with the use of an FSVM, an updated IFEG, or a set of Practice Guides are identified. Before this can be done however, a detailed review of the design and verification process in fire safety engineering is undertaken. The report then highlights how the use of each approach could impact the fire safety engineering design of buildings.

The design process is a process exercised by a designer in response to a design brief. (In the case of engineering design this designer is an engineer.) The process balances constraints and drivers associated with a project to develop detailed specifications of an artefact that performs the required function given in the design brief. Drivers are defined by the stakeholders of a project, including, e.g. sustainability, cost, or safety drivers; constraints are defined by the external world and may include, e.g. material performance or soft constraints related to the limits of knowledge and technical ability.

The specifications for the artefact that is the outcome of the design process are such that the proposed artefact represents an optimised balance between these drivers and constraints, whilst delivering the functionality required of it. The process of achieving this balance, the design process, may utilise any combination of guidelines or tools, as deemed suitable by the designer. In certain environments, there is an onus on the designer to demonstrate suitability of the tools chosen to carry out this process as well as to use these tools responsibly and within the bounds of the designer's own competence (respecting the constraints of their own ability) and the applicability of the tools. In fire safety engineering, the desired level of safety imposed by the stakeholders represents a driver in the design process.

Verification is a separate process from the design process, undertaken by a verifier. The verifier may be, but does not have to be, a separate individual or entity to the designer. The purpose of verification is to demonstrate based on available evidence that specific drivers or constraints have been respected. In the case of engineering, verification is typically applied to codified requirements and is used to prove that the artefact specifications resulting from the design process meet these requirements.

In fire safety engineering for buildings, the product of the design process is the specification of a Fire Safety Strategy (the artefact) for a building that conforms to the drivers and constraints specific to the project, including an agreed level of safety. The specifications for this artefact should then be verified to meet these levels of safety in a separate process. At this point, however, the practice of design and verification in fire safety engineering becomes confused in Australia and in many other countries.

Verification methods for fire safety typically prescribe specific scenarios against which a design should be checked. This method of verification inevitably influences the design process because the scenarios are a function of the design (i.e. the Fire Safety Strategy). Reference to the verification methods for fire safety engineering in the NCC 2019 in Australia perpetuates this. The result is that, whilst the FSVM defines a minimum number of scenarios, other scenarios may not be considered in the verification process, and those scenarios considered might not be appropriate given the characteristics of a

Verification is a separate process from the design process in fire safety engineering.

Codes define the societal goals, the functional requirements and the performance objectives. These may represent some of the drivers or constraints to which a design is forced to adhere. Guidelines describe accepted methods or means of developing a design.

specific design. As discussed elsewhere, this approach often results in the lowest common denominator for safety becoming the expected and accepted standard. New challenges need not be addressed, and emerging risks need not be considered. Clearly this situation is unacceptable.

A performance-based regulatory environment should include as a minimum three main components: i) codes, ii) guidelines and iii) evaluation / design tools. Codes define the societal goals, the functional requirements and the performance objectives. These may represent some of the drivers or constraints to which a design is forced to adhere. Guidelines describe accepted methods or means of developing a design. They may be referred to in the codes, although they do not have to be. The evaluation / design tools are tools that are used to quantify the results of the design process and to develop specifications for an artefact; and/or to verify that the artefact meets the required performance as dictated by the societal goals described in the code.

Meeting the Performance Requirements of the NCC/BCA in Australia can be achieved via three routes, via adopting a Deemed to Satisfy (DtS) Solution, via developing a Performance Solution, or via a combination of DtS and Performance Solutions. In the regulatory environment described above, the DtS Solution is a tool which can be used by the person specifying a Fire Safety Strategy (who should ideally be a competent Fire Safety Engineer) in much the same way as the tools required for development of a Performance Solution are.

When adopting a DtS Solution the onus is therefore on the person specifying the components of the Fire Safety Strategy to demonstrate that the building described in the design brief falls within the classifications of the building code that permits the adoption of that DtS Solution. This is where the need for verification lies. The DtS Solutions, ideally, should have been shown elsewhere to meet the Performance Requirements of the building code, and thus there is no need for further verification. When developing a Performance Solution for fire safety, however, there is significant breadth in the availability of approaches and tools for undertaking the design process, and thus there is a need for explicit verification that the artefact specified meets the Performance Requirements as defined by the code.

The 2019 version of the NCC contains only functional requirements. These are nominally referred to as Performance Requirements, however they are worded in such a way that verification of performance against them is impossible. Thus, when exercising a Performance Solution, the level of safety provided by an artefact that is specified according to the nearest available classification that enables a DtS Solution is the de facto performance requirement. This is incorrect, since the DtS Solutions have never been shown to provide an adequate level of safety for a building outside of the related classification. This is a product of the retention of prescriptive solutions in the performance-based building code and regulatory environment as these evolved from a prescriptive framework without a return to first principles of the design process. The DtS Solution is currently therefore not only a tool available for the designer but is also confused with Performance Requirements.

Further, as indicated above, the NCC/BCA permits a partial solution, with the adoption of a DtS Solution for some aspects of the Fire Safety Strategy, and the development of a Performance Solution for other aspects. This represents a deconstruction of the overall Fire Safety Strategy that obstructs the overall objective which is normally related to life safety of the occupants or firefighters. Thus, the Fire Safety Strategy as a whole is never subject to verification.

There exist three types of documents which have been reviewed in this report and which are intended to enable the design process: verification methods, guidelines and Practice Guides. In fire safety these are the Fire Safety Verification Method (FSVM) and Handbook published by the ABCB, the International Fire Safety Engineering Guidelines (IFEG) developed by various building code authorities around the world, and Practice Guides issued by the Society of Fire Safety (SFS) and others issued by organisations such as SFPE and state and territory authorities.

In the performance-based regulatory environment described, the FSVM, if it is to form a part of the regulatory environment, should ideally fit into the third component, as an evaluation tool for the purposes of verification of the design and Fire Safety Strategy. However, at present, by influencing the design process and perpetuating the use of a DtS Solution as a benchmark level of safety, it traverses the three parts of this environment and tries to serve the purpose of both a code and a guideline as well as an evaluation tool.

The IFEG should fit into the second component, as a guideline that is referenced in the code. Thus, it should be supported by and updated by regulatory authorities who rely on its use. It should provide support for the fire safety engineer in the use and appropriateness of tools and well as potential design approaches. At present the IFEG largely fulfil this role, although they are in need of revision.

The role of Practice Guides and Notes developed by the SFS and others is more obscure. They are not referenced in the NCC/BCA, and thus could fall under the classification of guidelines, or arguably design or evaluation tools for fire safety engineering. However, it is not clear what the purpose of these Practice Guides is, and for example the Practice Guide for facades includes a statement of Performance Requirements. Thus, parts of it clearly fall under the definition of a code. It must therefore be recognised and reinforced that the code should contain the governing definition of performance requirements.

Controlled phasing out of old editions, such as IFEG 2005, is recommended.

Conclusions and recommendations arising from this report are summarised thus:

1. That the Performance Requirements in the NCC/BCA be revisited and that the de facto use of a DtS Solution as an evaluation tool for an acceptable level of safety be carefully reviewed. This must be done in such a way that Performance Requirements are traceable to societal goals and functional requirements.
2. That the adoption of partial DtS / Performance Solutions through separation of the Fire Safety Strategy into requirements based on individual components be prevented and that the holistic nature of the Fire Safety Strategy be reinforced.
3. That the FSVM be revised such that it respects the independence of the design process and that it adequately verifies that the Performance Requirements are met.
4. That the IFEG be updated and that a controlled phasing out of old editions be undertaken regardless of the timeline for updating.
5. That the purpose of Practice Guides issued by professional societies and others be clarified and that it be ensured that these remain outwardly compatible with existing articles of reference.

1. Introduction

Australia needs nationally consistent guidelines for Fire Safety Engineers.

The aim of this Warren Centre Project and its research agenda is to provide a nationally consistent set of reform proposals to address:

- The most appropriate role or roles for fire safety engineers in building design and construction
- The most appropriate set of competencies required for the roles to be undertaken
- The accredited education programs and training required to achieve first-tier accreditation.
- The second-tier accreditation with one or more professional bodies for fire safety engineers to control competencies
- Common registration (or licensing) programs at the state and territory levels
- Common language for adoption of all these recommendations into state and territory regulations for building and construction.
- A plan for transition to full competencies and professionalism, recognising the need to lift standards, but at the same time being able ensure there is sufficient supply of fire safety engineers to serve the industry over the transition period.

This report is the third report of the current project and seeks to address the question of the utility and benefit of the Fire Safety Verification Methods which are currently being adopted into the regulatory environment here in Australia, as well as the International Fire Safety Engineering Guidelines and various Practice Notes.

> It is anticipated that many of the details of the review may be transferrable to other jurisdictions around the world.

Significant changes in materials, safety technologies and fire research necessitate updates in engineering methods.

In developing the brief for this report further and in setting a more detailed scope for this research task and report deliverable, the following were considered:

- The ABCB has agreed and issued a Fire Safety Verification Method (FSVM) for inclusion in the NCC for 2019 with an accompanying FSVM Overview or Handbook document.
- The FSVM has led to concerns by some about its technical content and application and as to whether it is an appropriate methodology which could ensure buildings of adequate safety or not.
- Some regulatory authorities, ABCB, AFAC and others such as SFS already have some Practice Guides or Notes to assist designers, and SFS is looking to provide further detailed Practice Guides for fire safety designers.
- Some practitioners have expressed a view that the IFEG should be more strongly referenced in the NCC or state and territory building regulations as the preferred fire safety engineering process document.
- However, the IFEG has not been updated since 2005, and there have been significant changes to materials, system technologies, and fire research more generally which suggest an update is necessary. It is understood that ABCB have that IFEG update on their agenda.
- Internationally, only New Zealand has a FSVM within their building code and regulations, but other countries such as Scotland and Spain are considering the introduction of a FSVM, and some countries like Sweden have a scenario- based fire safety engineering process document.
- This study and report were designed to examine the structure and process of the proposed FSVM and compare them with the process contained in the IFEG for fire safety design and analysis, as well as any relevant design and analysis processes included in SFPE and other Practice Guides.
- The report aims to identify the role played in FSE design and analysis, the utility and the benefits and deficiencies or other risks associated with the use of a FSVM, an updated IFEG, or a set of Practice Guides highlighting how each could impact on fire safety design, fire safety engineering and analysis, and the level of safety of buildings.
- The study was not required to undertake a detailed analysis of the highly technical aspects or data inputs within each document but rather the higher level technical and general issues related to their application to the process of performance-based design in Australia and their respective benefits.
- The research for this report was based on as source materials the current IFEG and proposed FSVM, as well as the ABCB Summary Report for the FSVM issued by ABCB, Practice Guides prepared by SFS, AFAC and others in Australia, recent conference papers on verification methods, and research papers by Dr Brian Meacham and others.
- In so doing, the current design and verification process in Fire Safety Engineering needed to be reviewed. This was to be done from an Australian perspective; however it is anticipated that many of the details of the review may be transferrable to other jurisdictions around the world.

This document first outlines the components of a performance-based regulatory environment, before reviewing the design and verification processes in fire safety engineering. It then goes on to discuss the use of DtS solutions as a benchmark for the current level of safety before finally identifying where the FSVM, the IFEG and practice guides fit into the performance-based regulatory environment described and the one that is in place in Australia. Finally, conclusions and recommendations are drawn.

The ABCB have proposed an updated FSVM Handbook.

1. Introduction

2. Components of a Performance-Based Regulatory Environment

According to Beck in the first Warren Centre project into Fire Safety Engineering[1] and to Meacham in collaboration with the SFPE,[2] a performance-based regulatory system comprises three components:

- The code or codes, which explicitly state the societal goals (the expectation from the building), functional objectives (how the building or systems function to meet the goals) and Performance Requirements (a statement of the level of performance that must be met in order for the building to meet the societal goals and the functional objectives) that are a reflection of the expectations of all relevant stakeholders in society of the expected level of safety provided by a building;
- Guidelines, standards or practices that describe accepted methodologies for compliance with the code. These may be referenced in the code but should be separate documents; and
- Evaluation and design tools which comprise accepted methods for assisting in the development, review and verification of designs. These may include the DtS provisions (if these are a route to compliance), or engineering standards, practices tools or methodologies as may be used for verification of compliance.

These components have been further expanded on and further detail added elsewhere,[3] however the basic structure remains largely unchanged. Note that the DtS, or prescriptive, solution can exist in the performance-based environment since it has by definition to be one of many along the spectrum of solutions which may be shown to meet the explicit Performance Requirements of the code or codes.

As was argued in the Education Report (task 3.1.1),[4] an item in addition to those proposed by Beck and Meacham is necessary for the implementation of such a code, and this is a clear and explicit definition of the knowledge and attributes necessary for the designer who is to deliver the Fire Safety Strategy. Given the structure of any performance-based regulatory system and its heavy reliance on competence, this is an unavoidable requirement.

> This has led to the current situation whereby there is significant confusion as to what constitutes design and what constitutes verification and where the boundary between these processes lies.

[1] Vaughan Beck, Claude Eaton, Peter Johnson, Ted Merewether, Caird Ramsay, John Richardson, Ross Freeman, Ray Lacey, Hamish MacLennan, Lawrence Reddaway, Ian Thomas (1989) Fire Safety and Engineering Project Report, the Warren Centre for Advanced Engineering, Sydney

[2] Meacham, Brian J.(1997) Concepts of a performance-based building regulatory system for the United States; proceedings of the fifth international symposium on fire safety science

[3] IJRCC (2010) Performance-Based Building Regulatory Systems Principles and Experiences, Brian Meacham (editor)

[4] Torero J., Lange, D., Horasan, M., Osorio, A., Maluk, C., Hidalgo, J., Johnson, P., (2019) Current Status of Education, Training and Stated Competencies for Fire Safety Engineers; The Warren Centre for advanced engineering, Sydney

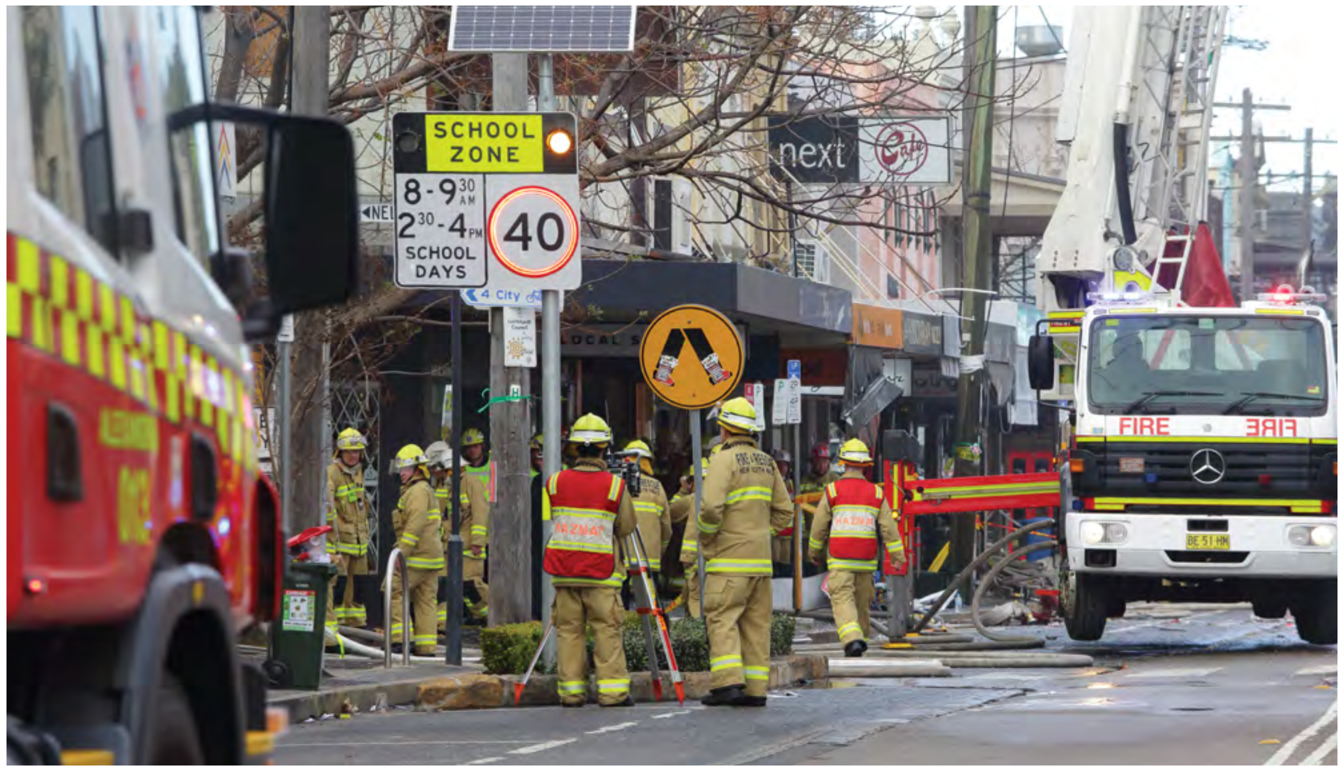
3. The Design Process

IN ORDER TO UNDERSTAND THE UTILITY AND BENEFIT OF DIFFERENT TOOLS AVAILABLE TO FIRE SAFETY DESIGNERS AND WHERE THESE FIT INTO THE REGULATORY ENVIRONMENT, IT IS NECESSARY TO DEFINE THE DESIGN PROCESS AND TO IDENTIFY WHERE THESE TOOLS FIT INTO THIS PROCESS.

Since the introduction of the first fully performance-based BCA96 in legislation in 1997, much of what has been labelled “fire safety engineering” has been more akin to verification of some elements of building design considered as “Alternative Solutions” or “Performance Solutions”. Often these alternatives to the DtS provisions have been put forward by architects or building surveyors, and fire safety engineers have had a limited scope to demonstrate that these alternative design solutions meet the Performance Requirements.

This has led to the current situation whereby there is significant confusion as to what constitutes design and what constitutes verification and where the boundary between these processes lies. There is therefore no recognition of the separation between these two processes. As a consequence of the current state in Australia, in only a limited number of projects have fire safety engineers worked closely and proactively with architects and engineers to become engaged in all phases of the design process to develop creative design solutions, before then going on to verify that these proposals meet the Performance Requirements of the codes.

This section discusses the design and verification processes in fire safety engineering, firstly through a review of the design process itself; followed by the verification process and then through a discussion of these processes applied to fire safety engineering.



Co-ordination of fire response in urban settings is complex.

3.1. THE DESIGN PROCESS

"Engineering design is the systematic, intelligent generation and evaluation of specifications for artefacts whose form and function achieve stated objectives and satisfy specified constraints." [5]

Every engineering project is subject to specific drivers, or objectives, and constraints. Drivers are quantifiable targets (e.g. functional specifications, maximum energy efficiency, minimum construction time, adequate or tolerable level of safety, etc.) while constraints are bounds that need to be respected (e.g. cost limits, materials that cannot be used, regulatory constraints, constraints of knowledge, etc.) Design is a process by which a designer will address the challenge of identifying the optimum balance between these often-competing concepts. The successful realisation of this process requires the consideration of how these drivers and constraints are expressed and how the final design may be implemented.[6] The outcome of the design process is the detailed specification of an artefact that successfully balances these drivers and constraints.

When the designer is presented with the brief of a project, the first step of the process is to identify what are the drivers and constraints.

The design process requires the use of many different tools that enable the designer to structure the drivers and constraints in a manner such that an optimised solution to the brief is demonstrable. The next step of the process is therefore for the designer to identify the tools necessary for the optimisation process. These tools comprise a combination of:[7]

- a representation of the artefact proposed that allows the design problem including the drivers and constraints to be recast accordingly for evaluation; and
- problem-solving techniques that allow the enumeration of various design alternatives.

The person exercising the design process, the designer, is an individual who by training or practice has demonstrated the capacity to design. This not only includes sufficient mastery of the tools but also an understanding of how to balance the drivers and constraints to deliver and demonstrate in an explicit manner an optimal solution.

Every engineering project is unique.

[5] Dym, C. and Brown, D. (2012) Engineering Design; Cambridge: Cambridge University Press ISBN: 9781139031813
[6] A. Law, N. A. Butterworth, Jamie Stern-Gottfried and Y. Wong (2012) Structural Fire Design: Many Components, One Approach, 1st international conference on performance based and life cycle structural engineering PLSE 2012
[7] Dym, C. and Brown, D. (2012) Engineering Design; Cambridge: Cambridge University Press ISBN: 9781139031813

Every engineering project is subject to specific drivers, or objectives, and constraints.

Note that the tools used in the design process many times serve to simplify the design in such a manner that the tool can be confused with the process. Codes and standards are a tool for the designer. However, in some cases, these can be so restrictive that the process of design can become an apparently minor exercise. For example, the use of span-capacity tables in structural engineering is an example of a simplified process; one that may result in the specification of an artefact that satisfies specific drivers related to the factored bending or shear stress applied to an element whilst respecting constraints related to material strength and available section sizes from a given manufacturer.

Depending on the problem, the design process can be simple and managed by a single designer or be complex and managed by a team that as an ensemble compiles all necessary knowledge and attributes. If the object of the design is of such importance and complexity, as is the case with buildings, the designer should be a professional, regulated by means of a rigorous assessment of knowledge, skills and attributes. The need for a process of professional regulation in Fire Safety Engineering is discussed in detail in the report into task 3.1.1 (The Education Report) of this Warren Centre project.[8] The design process is always the responsibility of the designer.

3.2. THE VERIFICATION PROCESS

ISO 9000 defines verification as "confirmation, through the provision of objective evidence, that specified requirements have been fulfilled".[9] The ABCB defines a verification method in simple terms as:

"A Verification Method is a means of demonstrating that a Performance Solution complies with the relevant Performance Requirement."[10]

In other words, verification is the process whereby it is proven that any part, or the ensemble, of a system as designed conforms to its requirements or specifications.[11,12] It is the process of checking that the constraints have been respected while the drivers have been achieved.[13] The outcome of the verification process is nothing more than confirmation of this.[14] If this cannot be evidenced by verification, then the design process should be iterated. Verification is a process separate from, or parallel to, design. As a separate process, verification should not influence the design process. Verification is the responsibility of the verifier; who may or may not be a separate entity from the designer.

[8] Torero J., Lange, D., Horasan, M., Osorio, A., Maluk, C., Hidalgo, J., Johnson, P., (2019) Current Status of Education, Training and Stated Competencies for Fire Safety Engineers; The Warren Centre for advanced engineering, Sydney
[9] AS/NZS 9000:2016 Quality management systems – fundamentals and vocabulary
[10] ABCB (2018) NCC Volume One: Energy efficiency provisions handbook
[11] NASA Systems engineering handbook; SP/2007-6105
[12] NSW Government, Transport for NSW; TS10506:2013 AEO Guide to Verification and Validation
[13] Chandrasekaran, B. (1990) Design Problem Solving: A Task Analysis, AI Magazine Volume 11 Number 4
[14] NASA Systems engineering handbook; SP/2007-6105

Barangaroo towers, Sydney.

Verification methods generally fall under four categories: analysis, demonstration, inspection and testing.[15] Verification in the form of analysis is typically done during the concept, development and early production phases of the design process.[16] Whereas other types of verification are typically done following construction or assembly and during use of the final product.

The implicit or explicit use of verification methods in design has existed since the inception of the engineering practice and is currently ubiquitous in engineering design. For example, in the NCC in Australia, combinations of the DtS clauses are considered verification methods associated with the individual Performance Requirements.[17] Examples of verification methods in other engineering disciplines, in particular structural engineering, exist, e.g. the verification methods related to structural reliability and robustness as referenced in the NCC of Australia.[18,19] The verification methods for robustness and reliability are used for the verification of structures based on loading requirements which are prescriptive in nature and in the case of the reliability verification method, reliability targets which are incorporated in the NCC. Other examples include the verification of ultimate limit state criteria according to the partial factor method in the Eurocode.[20]

All of these verification methods have in common that they address the verification of particular clauses or objectives in the codes which reference them, and all of these have in common that they do not interfere with the design process. This is correct, since verification, as discussed above, is a separate process from design. Where design has as its objective the delivery of specifications for an artefact which balances the stated drivers and constraints, verification has as its objective the confirmation that the artefact which is specified meets these performance criteria.

Common to all of the above-mentioned verification methods are two fundamental characteristics. First each verification method targets a single performance requirement which is explicitly defined and therefore verifiable. Second, the use of these verification methods does not interfere with the design process.

[15] NASA Systems engineering handbook; SP/2007-6105
[16] NSW Government, Transport for NSW; TS10506:2013 AEO Guide to Verification and Validation
[17] ABCB (2019) National Construction Code
[18] ABCB (2015) Structural Reliability Handbook
[19] ABCB (2016) Structural Robustness Handbook
[20] H. Gulvanessian, J.-A. Calgaro, M. Holický and Haig Gulvanessian; (2012) Designers' Guide to Eurocode: Basis of Structural Design: EN 1990, Second edition

3.3. THE DESIGN PROCESS IN FIRE SAFETY ENGINEERING

The design process in Fire Safety Engineering should in principle be very similar to that described above, with specific drivers and constraints identified for a project and the use of different tools to perform the optimisation. Nominally, fire safety engineering in many jurisdictions is undertaken in an environment that facilitates both a prescriptive approach and a performance-based approach (both as a means of meeting the performance requirements).

A performance-based regulatory environment is based on enabling regulatory acceptance of a design contingent on the ability to demonstrate that specified objectives have been met. Conversely, a prescriptive regulatory environment is based on the regulatory acceptance of a design contingent that a strict set of rules have been followed. In the former, there is an explicit demonstration that objectives have been met meaning, in the case of Fire Safety Engineering, that as a consequence of a Fire Safety Strategy an acceptable level of safety is demonstrably achieved. Whereas in the latter, the achievement of this acceptable level of safety is never demonstrated and is implicit by adherence to accepted classifications and solutions. In a comprehensive performance-based approach, there is therefore the need for quantified or quantifiable parameters that set the acceptable level of safety. These must be quantifiable so that compliance of a design to the required performance parameters can be verified.[21]

In Australia, as in other countries, Performance Requirements are given in the National Construction Code that must be met. The

All of these verification methods have in common that they address the verification of particular clauses or objectives in the codes which reference them, and all of these have in common that they do not interfere with the design process.

[21] Beck, Vaughan (1997) Performance-based Fire Safety Engineering design and its application in Australia; proceedings of the fifth international symposium on fire safety science

route to meeting these is either to exercise a design according to the DtS provisions in the National Construction Code (as part of what may be termed a prescriptive approach based on the above description, but which is in fact simply another means of arriving at specifications for a fire strategy that have elsewhere been deemed to meet the performance requirements) or to exercise a performance solution. Many construction codes around the world include these, or very similar, Deemed to Satisfy (DtS) provisions for satisfying specific objectives. According to the ABCB, the DtS Provisions represent a 'recipe book' solution where the required performance of each design element is described in detail. They are included as a route to compliance for a designer that does not want to develop a new means of achieving the Performance Requirements,[22] in other words in instances which do not warrant the development of a performance solution.

When exercising a DtS Solution this needs to be combined with evidence of suitability and / or expert judgement. When exercising a performance-solution this needs to be further combined with a combination of either a comparison of the resulting level of safety with DtS provisions, in accordance with the fire safety verification method (FSVM) of schedule 7 of the NCC 2019, or some other verification method.[23] The role of the FSVM in the design and verification processes will be discussed in the next section.

In fire safety, however, the DtS provisions do not describe the required performance of each design element and are in fact specifications for those design elements that comprise a Fire Safety Strategy for specific classes of buildings. These specifications should have been demonstrated elsewhere to provide an adequate answer to a specific set of variables of the optimisation process, and thus respond to the societal constraint of guaranteeing a tolerable level of safety for building occupants, emergency responders and the general public.

However, solutions generally cannot apply to all problems; therefore, the process of adoption of a DtS Solution has a critical component, which is namely the classification. (Here classification refers to the specific features of the building which dictate which of the DtS solutions on offer may be adopted if following the DtS approach.) The classification corresponds to the specific buildings to which the solution applies. This classification introduces limitations, for example the building height, its use, surface area, location, materials of construction, etc. In application the classification also imposes assumptions about the expected performance of certain aspects of the Fire Safety Strategy, thus limiting the fire scenarios to which the building could be exposed, for example no vertical flame spread for high rises, acceptance of total loss for buildings with no suppression or little to no structural resistance to fire, a defend-in-place strategy for hospitals, etc.

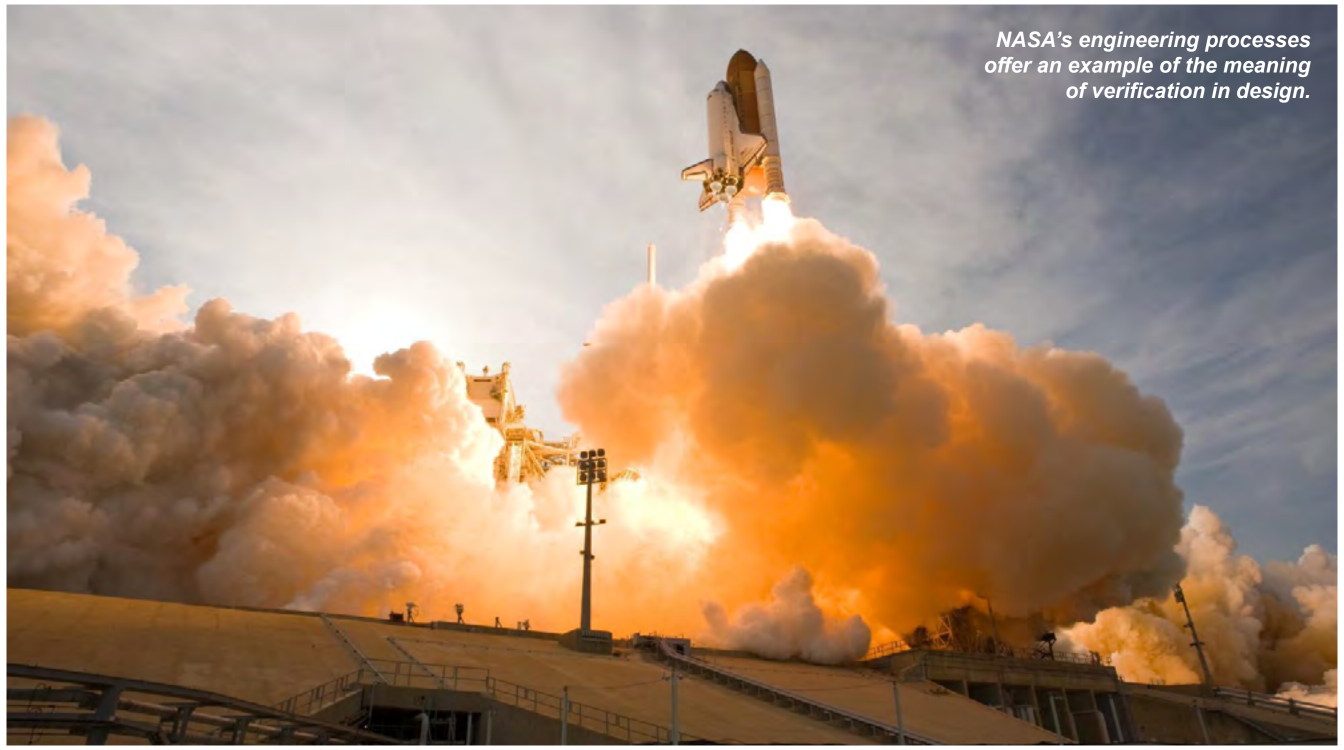
An approach to design that is based on a DtS Solution as a means of meeting the designer's social responsibility to provide infrastructure that is safe from fire only works when the building that is the subject of that design falls within the scope of the classifications available in codes.[24] It should be the role of the engineer responsible to demonstrate that this is the case and that the DtS Solution is suitable.[25]

[22] ABCB (2018) NCC Volume One: Energy efficiency provisions handbook
[23] ABCB (2016) Compliance with the NCC infographic
[24] Torero J., Lange, D., Horasan, M., Osorio, A., Maluk, C., Hidalgo, J., Johnson, P., (2019) Current Status of Education, Training and Stated Competencies for Fire Safety Engineers; The Warren Centre for advanced engineering, Sydney
[25] Note that in Australia, as in many other jurisdictions, this task is very rarely adopted by a person with competence in fire safety engineering

This approach results in a narrow range of possible solutions to the problem of ensuring fire safety of a building. It is a "one size fits all" approach that is founded on the basis that there are minimal variations between buildings and thus a solution that works for one can work for others that fall under the same classification. As noted above, this means that these solutions are never explicitly demonstrated in application to meet any of the Performance Requirements of the building regulations, but rather it is widely accepted that they provide a level of safety satisfactory to all relevant stakeholders. This can be, and is, tolerated in most cases based on the collective experience of the fire safety profession of what has worked in the past. Since adequate safety is never demonstrated explicitly, in the case of new projects relying on prescriptive code-based solutions, it is assumed.

As alluded to above, the restrictive nature of prescriptive or DtS design results in the risk that the apparent magnitude of the process overshadows its importance or complexity. In the case of Fire Safety Engineering, prescriptive design is very detailed and restrictive. It therefore leaves very little space for decision-making leading to the misconception that prescriptive design requires little skill. This is not the case, and in a prescriptive environment or when working with DtS Solutions, it is the responsibility of the designer to demonstrate that the "one-size-fits-all" solution is applicable to the problem at hand. Further, this misconception has resulted in an environment for practice where the designer can be poorly regulated, with the restrictions imposed by the codes obscuring the poor regulation of the individuals practising. This was discussed in the Education Report produced by The Warren Centre in early 2019.[26]

Performance-based design is applicable either when buildings fall outside of the classifications available in the codes or when



NASA's engineering processes offer an example of the meaning of verification in design.

Photo credit: NASA/Sandra Joseph, Kevin O'Connell
Image # : sts127-s-038 | Date: July 15, 2009

[26] Torero J., Lange, D., Horasan, M., Osorio, A., Maluk, C., Hidalgo, J., Johnson, P., (2019) Current Status of Education, Training and Stated Competencies for Fire Safety Engineers; The Warren Centre for advanced engineering, Sydney

DESIGN AND VERIFICATION – A GLIMPSE INTO THE NASA PROCESS

NASA uses the Systems Engineering (SE) engine to drive the design process. The SE engine consists of three main components: system design processes, technical management processes and product realisation processes. System design processes define the expectations, generate technical requirements, and develop a technical solution capable of meeting the specified requirements. Technical management processes are used to advance the design process, assess progress, and aid in decision making processes. Product realisation processes are used to implement a design and verify and validate attainment of stakeholder requirements. Verification and validation methods fall under product realisation processes and are typically defined in the early stages of the design process. It is important to highlight that within NASA, verification and validation do not mean the same. Verification is meant to show compliance with requirements, whereas validation is meant to demonstrate effectiveness and suitability under realistic conditions. In essence, verification ensures that a design process addressing the stakeholders' expectation and requirements was carried out correctly.

NASA identifies four types of methods of verification: analysis, demonstration, inspection and test. In order to conduct any sort of verification it is important to define a verification program which includes the procedures to be followed and the reporting to be conducted. A verification program may include verifications at different levels, ranging from individual components all the way up to the systems level. Outputs of the verification processes are typically recorded in requirements compliance/ verification matrices that allow tracing compliance from the individual component all the way to the systems level.

Sources:
- NASA Systems Engineering Handbook
- Expanded Guidance for NASA Systems Engineering, Volume 1: Systems Engineering Practices

the narrow solution afforded by the DtS provisions is unsatisfactory to one or more of the stakeholders of the project. Thus, a DtS Solution would not be evidently suitable. In this case, since a variation from the prescriptive codes is to be applied, the spectrum of possible solutions widens. However, since either one, or both, of the classification and the design solution have now departed from the boundaries of the prescriptive codes, the implicit assumption of achieving a tolerable level of safety based on these prescriptive codes no longer applies. There is insufficient evidence for these complex buildings or these bespoke solutions to be able to make any assumptions or implicit determinations with regards to the level of safety. Complex, novel, or unusual aspects of specific buildings can challenge all aspects of the Fire Safety Strategy in unforeseen ways, and since the Fire Safety Strategy is intrinsically holistic in its implementation the need to explicitly demonstrate and evaluate the safety of the solution arises.[27] The role of the engineer in this instance extends to being not only able to evidence applicability of the solution chosen; it now includes responsibility for development of said solution.

Moving further from the influence of small extrapolations from the DtS requirements towards a performance solution, the design process is of course unaffected and remains the process of achieving a balance between drivers and constraints. However, the tools at the fire safety engineer's disposal to achieve this balance change. No longer applicable are the codified DtS specifications which are widely accepted to satisfy the performance criteria. Now the fire safety engineer must adopt some form of calculation method in order

[27] Van Coile, R., Hopkin, D., Lange, D., Jomaas, G., Bisby, L. (2018). The need for hierarchies of acceptance criteria for probabilistic risk assessments in Fire Safety Engineering. Fire Technology, 2018. https://doi.org/10.1007/s10694-018-0746-7

to demonstrate a balance between the drivers and constraints within which they are working. This may take the form of, for example, the development of a model or models and then their subsequent manipulation in the form of carrying out simulations to calculate the impact of different scenarios on specific aspects of a Fire Safety Strategy. This might include, for example the use of Computational Fluid Dynamics (CFD) models to determine visibility or toxicity levels for comparison with the results of evacuation models to demonstrate the potential for safe evacuation of building occupants. Alternatively, it may take the form of a finite element analysis of the structure to evaluate the impact of a fire on the structure until burnout. Also, it may take the form of simple hand or spreadsheet-based calculations to perform similar analyses. It must be the responsibility of the engineer (designer) to select the most appropriate tools for this analysis as part of this process.

VERIFICATION AND VALIDATION IN TRANSPORTATION INFRASTRUCTURE ASSETS

The Asset Standards Authority of Transport for New South Wales (TNSW) define verification as the "process performed to ensure that the output of a design stage or stages meets the design stage input requirements". Verification goes hand in hand with validation, defined as "the process to confirm that the final product delivers defined operations and user requirements for its intended use". According to TfNSW the outputs of the two processes provide assurances as part of product or safety case documentation that the requirements stipulated in the design stage have been met. The two processes run throughout the life cycle of a system and are used to ensure that the specifications of the system and the components of which it is an ensemble are, and continue to be, met.

TfNSW stipulate that any authorised engineering organisation have verification and validation processes in place that are appropriate to the engineering service or product that they supply. They have requirements for the development of a verification plan that includes various verification activities, including any combination of inspections, analyses, demonstrations, tests, all leading ultimately to certification. The verification plan comprises any number of these different tasks as appropriate for the life cycle of the asset and has as its goal the verification that a system as designed is capable of meeting all of the requirements stipulated at the start of the design process. The verification process should be linked to a requirements verification and traceability matrix, which links evidence of verification to the individual requirements.

Source:
- TS 10506: 2013 AEO Guide to Verification and Validation Version 1.0

Transport for NSW is undertaking major rail expansion in metropolitan Sydney.

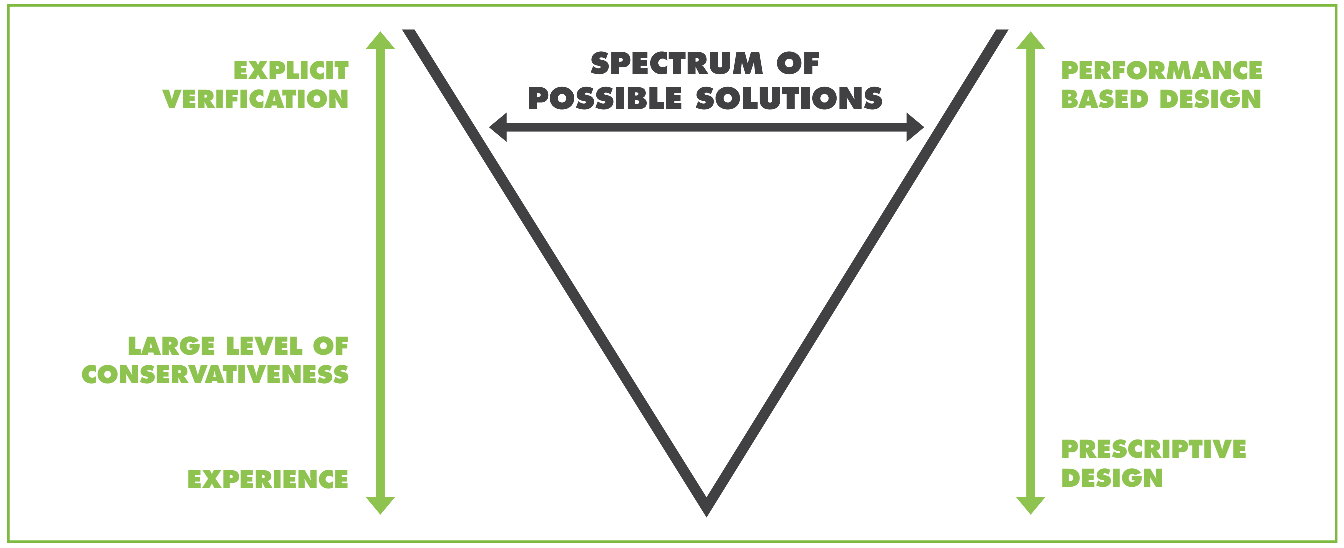


Figure 1: Expanding spectrum of possible solutions with performance-based as opposed to prescriptive design.

The successful adoption of a performance-based approach to design results in an expanded spectrum of possible solutions in comparison to a prescriptive approach alone, as illustrated in Figure 1. The performance-based design process is an open-ended process as opposed to a closed process in that there are usually many acceptable solutions to the problem.

Guidelines and Practice Guides can be used by practitioners at various stages of the design process. The specific stage at which these fit depends on their subject matter and the intended outcome. Guidelines, referenced in standards or building codes, are tools that present best practices for designers to use when relevant. Guidelines cannot be compulsory, because they are just an aide to the designer. They should be regularly updated. If guidelines were to become obsolete or inappropriate, it remains the responsibility of the designer to determine whether they are fit for purpose and whether to use them or not and discard them. Given that guidance can be issued by governments but can also come from manufacturers, professional bodies and organisations such as the fire service or insurance bodies, within the boundaries of the designer's professional duties it remains the prerogative of the designer to make best use of this information. It is the designer's professional judgement whether and how to use these guidelines or not. Practice Guides serve a similar purpose to guidance documents, and while these arguably fall outside of the regulatory environment they are no more subject to the need for the professional to demonstrate their suitability for the task at hand than guidance documents.

It is worth noting, at this stage, that it is common to confuse the design process with the application of the codes and standards. As discussed above, in a performance- based regulatory environment, codes, or parts of codes, are tools which enable the design process as opposed to a representation of the process itself.

All of the above examples of tools in the design process serve to deliver specifications for an artefact, namely the Fire Safety Strategy, which satisfies the design criteria laid out at the outset. The only difference in the examples is the tool that the engineer decides to use for executing this process. Only once a design has been delivered can the process of verification that the design achieves the required performance objectives begin.

COMPLEX LEGAL AND REGULATORY ENVIRONMENT

The scope of this report does not extend to a review of the full legal and regulatory environment governing Fire Safety Engineering in Australia, but the Victorian Civil & Administrative Tribunal (VCAT) decision[i] on the Lacrosse fire issued 28 February 2019 illuminates the complex and overlapping issues currently being discussed in the Australian building industry.

At about midnight on Monday, 24 November 2014, a carelessly discarded cigarette caused a balcony fire at the Lacrosse apartment tower at 673-675 La Trobe Street, Docklands, Melbourne. From level 8, the fire moved rapidly up to the roof of the apartment tower. More than 400 residents were rapidly evacuated, and no injuries were experienced, but the property loss exceeded $12 million. The building owners via their Owners Corporations sued the builder, the building surveyor, the architect and the fire engineer.

In the decision of the Tribunal, Judge Woodward reviewed the legislative and compliance regime and considered how the contracts specific to the Lacrosse project affected the responsibilities of the various parties including the builder, the building surveyor, the architect and the fire engineer.

Issues raising liabilities in the case included:

- **Warranties** for suitability of materials, compliance with the law, and fitness for purpose. These warranties were both express and implied;
- Necessity to **exercise due care and skill**;
- The **reasonableness of "peer professional opinion"** in the industry regarding materials selection and professional services;
- Design **defects**;
- Compliance to the **contract standards** and to the **Building Code of Australia**; and
- The conduct of professionals resulting in representations that were **misleading and deceptive** in contravention of Australian Consumer Law.

Judge Woodward held that the specification and installation of aluminium clad panels (ACPs) breached the warranties of suitability of materials, compliance with the law and fitness for purpose and did not satisfy the "Deemed-to-Satisfy" provisions of the BCA.[ii] He confined the critique of ACPs and said, "[T]hese reasons should not be read as a commentary generally on the safety or otherwise of ACPs and their uses."[iii] He deferred future particular applications as "a matter for regulators and building engineering experts." He also confined his judgment saying that these "findings have been informed by the particular contracts between the parties in this case and by events occurring in the course of the Lacrosse project that may or may not be duplicated in other building projects."[iv]

[i] Owners Corporation No.1 of PS613436T v LU Simon Builders Pty Ltd (Building and Property) [2019] VCAT 286.
[ii] Ibid at [7]
[iii] Ibid at [10].
[iv] Ibid at [11].

Fire Safety designs are undertaken in a complex environment.

3.4. VERIFICATION IN FIRE SAFETY ENGINEERING

When adopting a DtS Solution, verification is not required of the DtS Solution itself, since this has already been deemed to result in a tolerable level of safety. What requires verification, as discussed above, is that the classification (which implies limitations on the applicability of that DtS Solution) has been respected. For a DtS Solution, it is therefore the role of the designer to demonstrate explicitly that the codes and standards being used can be applied to the specific building. This implies respect for the classification, its assumptions and limitations, as well as the correct implementation of the prescriptive solution. Once the designer has demonstrated this, then the performance explicitly defined through the development of the codes and standards may be assumed to have been met by the specific building. In a professional framework, the responsibility for this explicit demonstration should rest with the professional. In practice, in Australia, the designer and the approval authority, or certifier, often share this responsibility. The current role of the authority is to certify that the designer has classified the building correctly and that the DtS Solution has been implemented adequately.

A DtS Solution may therefore be considered as an option if and only if the building being designed fits, or can be modified such that it fits, within the available classifications in the NCC/BCA. Then this is a valid solution.

A small departure from the DtS (for example trade-offs to achieve a small increase in the number of possible solutions) may arguably be achieved through the adoption of a large level of conservatism; however, a significant departure from the DtS is accompanied by a need for explicit verification of the level of safety achieved by the design.

For any building code to enable a performance-based approach and therefore to call itself a true performance-based code, it must include an explicit statement of the Performance Requirements against which verification can be made. These must be linked to functional objectives and societal goals for fire safety.

Further, it must be noted that the need for explicit verification of the level of safety in turn brings with it a need for greater competence of the fire safety engineer implementing this design as opposed to the prescriptive solution, as well as of the person certifying the design.[28] It also imparts a significant onus on the engineer in performing their duty to society as well as to other stakeholders on a specific project. The means and complexity of the demonstration of compliance therefore varies with increasing departure from prescriptive regulation.

> The verification process should not influence the process of developing the Fire Safety Strategy.

[28] Torero J., Lange, D., Horasan, M., Osorio, A., Maluk, C., Hidalgo, J., Johnson, P., (2019) Current Status of Education, Training and Stated Competencies for Fire Safety Engineers; The Warren Centre for advanced engineering, Sydney

Fire Safety verification occurs throughout the life cycle of a building.

In fire safety, verification methods manifest both early in the design process, in the form of analyses undertaken; or during the final stages of construction and later during occupancy while undertaking routine performance checks of the different components. For example, during the design process, referring to Structural Fire Safety Engineering for example, identification of collapse based on models is very challenging and most engineers will look for runaway or non-convergence of the model.[29] Both of these criteria are examples of simple verifications that are used to demonstrate compliance with requirements related to collapse of structures. During the final stages of construction or during occupancy examples of verifications include these examples:

- The use of clean agent fire suppression systems relies on agent containment within the enclosure, so leakage of the enclosure is verified by fans that develop the pressure to test leakage.
- Smoke management systems in stairs have pressure sensors to monitor the evolution of the pressure.
- Sprinkler systems and their pumps are subject to numerous tests that guarantee performance, and some smoke detectors have fault indicators that indicate when the detector is not powered.

Notwithstanding the need for verification, the verification process should not influence the process of developing the Fire Safety Strategy. The Fire Safety Strategy is the outcome of the design process and therefore incorporates a series of variables that are being optimised, and it is the designer who is responsible for adequately performing this optimisation.

[29] D. Lange, L. Boström; A round robin study on modelling the fire resistance of a loaded steel beam; Fire Safety Journal,2017; http://dx.doi.org/10.1016/j.firesaf. 2017.05.013

4. DTS as a Performance Requirement for Verification

In areas such as structural engineering, prescriptive components of the design framework, such as the definition of loads, are the explicit outcome of research that demonstrates that for a certain classification the choice of loads prescribed by the building code are within the bounds of what will be expected for a building meeting the classification requirements. This can, and normally does, include societally acceptable factors of safety. The demonstration of tolerability of a DtS Solution should be explicit for the development of the codes and standards. Once a solution has been demonstrated to fulfil the desired objectives, then it can be inscribed within building codes, and any subsequent application is explicitly acceptable so long as the DtS Solutions can be evidenced as appropriate. In a similar manner, when component performance has been demonstrated then a standardised procedure for performance assessment can be constructed into a standard.

In the area of Fire Safety Engineering the process of code development does not necessarily follow the logical approach adopted by some other disciplines of delivering a pre-defined solution as a function of an explicit demonstration of performance. It is often founded on the experience of the profession[30] or some other apparently arbitrary criteria. For example, limitations of compartment areas in Approved Document B in England are based on a survey of post-war buildings in the UK.[31] Also, the escape distances inscribed in codes around the world have at their origin the evacuation of a theatre in Edinburgh, UK in 1911.[32] The use of so-called 'magic numbers' in fire safety engineering is a well-known practice that has had an inexplicable influence on the profession for nearly a century.[33]

In general, prescriptive codes are separated from the nature of the building design, and any research implemented tends to focus on the implementation of countermeasures that are deemed adequate for a building within the classification. This is how prescriptive rules are developed for example for sprinkler design, for detection and alarm, passive fire protection, etc. This approach distances the implementation of prescriptive fire safety from the design process because the objective changes from designing a building to be safe to designing a sprinkler system that can be shown to control a fire with the characteristics that may result from the classification at hand. This is an abstract decomposition of Performance Requirements for a building's Fire Safety Strategy into detailed specifications of the individual components implemented into this strategy. The holistic nature of the design process is then lost, and the role of the overall Fire Safety Strategy in prescriptive design becomes obscure. A prescriptive design for fire safety will state that a building belonging to a certain classification will incorporate maximum acceptable travel distances, sprinkler systems with a given performance, a specific detection and alarm system and some level of passive fire protection. What will be the outcome of this implementation on the overall safety of a specific building is never tested, and therefore it is argued that prescriptive fire safety is an adoption of an unknown level of safety.

[30] Van Coile, R., Hopkin, D., Lange, D., Jomaas, G., Bisby, L. (2018). The need for hierarchies of acceptance criteria for probabilistic risk assessments in Fire Safety Engineering. Fire Technology, 2018. *https://doi.org/10.1007/s10694-018-0746-7*
[31] Lennon, T. (2015) Compartment sizes – are they still fit for purpose? Presentation given at BRE fire conference 2015, available from: *http://www.bre.co.uk/filelibrary/ Fire%20Research%20Conference%202015/4-BRE-Fire-Conf-2015*---Compartment- Sizes.pdf, accessed 9th January 2019
[32] Ross, Liam; Invitation & Escape The Architecture of Fire Safety Regulation
[33] Law, M. & Beever, P. (1995) Magic numbers and golden rules Fire Technology 31:77. https://doi.org/10.1007/BF01305269

Fire Safety regulation protects buildings and responders.

4. DTS as a Performance Requirement for Verification

Many of the Performance Requirements for fire safety in the NCC are not defined in such a way as they themselves can be used as an objective for design. They are too vague and abstract for this. (This is true of the Performance Requirements as stated in many jurisdictions, examples of which are given in Appendix 4.). This results in the DtS Fire Safety Solution for a building that falls within the bounds of the nearest available classification being the de-facto performance requirement against which performance-solutions for buildings that fall outside of the classifications are verified. This is incorrect, since the DtS Solutions have never been shown to provide an adequate level of safety for a building outside of the related classification. In fact, in a calibration of the ABCB's proposed FSVM, several simple buildings which comply with the DtS provisions of the NCC/BCA were analysed, and it was found that they did not meet the requirements or the acceptance criteria of the FSVM. In addition to this, they were shown not to meet the risk tolerance criteria set by the ABCB in that same work. This highlights the importance of objectively setting of performance requirements independently of the DtS or any other historical approach to fire safety and the dangers of continued reliance of the DtS as a benchmark level of safety for performance solutions.[34]

The DtS requirements have, as their origin, previous evolutions of building regulations which were in place prior to the advent of Performance Based regulations. These DtS requirements represent detailed specifications for components of a Fire Safety Strategy that were for the most part based on experience of the profession and not on a detailed analysis of the performance of the overall strategy. For compatibility these regulations were retained as the DtS requirements in performance-based environments, and the adoption of these as the specifications of the components of a Fire Safety Strategy in a building is one route to demonstrate compliance with the regulations.

Since the impact of each component of a Fire Safety Strategy on the overall safety of the building is not defined explicitly by a prescriptive solution, an equivalent approach cannot be quantified. Small extrapolations such as exceeding travel distances can be demonstrated to have no impact on egress by using complex analytical tools. For example, the calculation of egress times from a compartment can be quantified (Required Safe Egress Time) and tested against times to attain tenable conditions (Available Safe Egress Time), and it can be shown that the ASET > RSET. This might satisfy expectations of safety, nevertheless these calculations require many assumptions (e.g. fire growth rates), calculation parameters (e.g. displacement velocities) and model precision (e.g. zone model vs. computational fluid mechanics model) and have no benchmark against which they can be compared. An increased travel distance alone will always lead to a larger RSET, thus will never be as safe as the code compliant travel distance. Equivalency is therefore not possible, and the only alternative is to establish the overall impact on the Fire Safety Strategy.

The question therefore arises as to what constitutes an adequately or tolerably safe design. It is here that the need to re-emphasise the role of the Fire Safety Strategy as the artefact being designed becomes clear. And along with that the need for an explicit definition of the Performance Requirements and societal goals in addition to the functional requirements already included in codes. This is a necessary and urgent reform for the fire safety community.

[34] Fire Protection Association Australia (2017) Australian Building Codes Board Fire Safety Verification Method Calibration Project Draft Final Summary Report

5. The Role of IFEG, Practice Guides and the Verification Methods in Design

> It is clear that the Australian code is not a true performance-based code.

In comparison to the components of a performance-based regulatory environment as outlined in section 3, the Australian code comprises the following components:

- The NCC/BCA building code describes Performance Requirements, which are the legal requirements referenced in state and territory building regulations, and detail how a building is expected to function to meet the societal goals. According to the definition given above, these more closely resemble functional objectives. As described in former sections, they are not written in such a way that they can be referred to for verification. This fact is acknowledged in the Schedule 7 FSVM of the NCC 2019;[35]
- Various guidelines and standards are referenced in the NCC, for example the International Fire Safety Engineering Guidelines or various testing standards for component performance are referenced in the DtS specifications;
- The only design tool referenced in the NCC is the DtS specifications. However, in the NCC 2019 these are confused with both verification methods themselves and with Performance Requirements. Other standards, such as fire resistance testing standards or reaction to fire testing standards are referenced. The evaluation tool referenced in the NCC is the FSVM in Schedule 7; this shares the limitation of referring to the DtS specifications as the desired performance requirement.

Based on the above, it is clear that the Australian code is not a true performance-based code. Specifically, it lacks explicit Performance Requirements which can be linked through functional objectives to societal goals. It also confuses the role of the DtS between a design tool, which is correct, and a performance requirement, which is incorrect.

A detailed description of the FSVM, the IFEG and Practice Guides are given in appendices 1, 2 and 3. The following subsections contain a brief discussion about these documents, comparing them with the regulatory framework described, the current framework in Australia and discussing their role in the design and verification processes described previously.

[35] ABCB (2019) National Construction Code

5.1. THE ROLE OF THE FSVM

The concept of a verification method for fire safety has been introduced in New Zealand and is in the process of entering the regulatory structure in Australia.[36] A Fire Safety Verification Method (FSVM) should ideally fit into the third component of the system described by Beck and Meacham, as an evaluation tool for the purposes of verification of the Fire Safety Strategy. Based on the discussions above, it should be a separate process from the design process and should be a method for verification of individual Performance Requirements of the Fire Safety Strategy.

While effort has been made to create adequate verification processes, it is not clear that the principles of verification described previously have been considered adequately. In Fire Safety Engineering there are many areas where a verification is important and valid. Verification might be necessary to establish if complex tools have been used appropriately. A well-known case of concern has been the use of Computational Fluid Dynamics tools. The question here is to separate the use of the tool (specific objective) from the application of the tool for design. The tool has components (i.e. grid resolution, treatment of boundary layers, combustion models, radiative models, etc.) that can have a major impact on the result and that might need to be checked. The objective is to avoid having to reproduce the computations fully and instead to propose a verification approach that gives sufficient guarantees that the model has been applied correctly.

In contrast, the decision of how the model will be used to establish the performance of the design, or Fire Safety Strategy, is a matter for the designer and cannot be verified. For example, the choice of how a fire can be constructed to challenge the performance of a building design has to be the prerogative of the designer because such fires are a result of a design. Without a Fire Safety Strategy, the fire will follow a very different course than with a Fire Safety Strategy. Thus, the designer has, with their decisions, the capacity to alter the course of the event. Testing a design with prespecified design fires as means to verify the decisions of the designer is a contradiction in itself because through the design process the designer will determine the nature of the possible fires. This is the same for egress scenarios and smoke management calculations.

The FSVM included in Schedule 7 of the NCC 2019 however unduly influences the design process by prescribing scenarios. Further, by comparison of any performance solution with the nearest available DtS Solution, it in fact traverses the three parts of this framework. It perpetuates the DtS Solution as a performance requirement, which as was discussed above is an incorrect application of DtS, promotes confusion between them as a tool for design and a codified level of safety. It also falls under the definition of a guideline and an evaluation tool as defined above.

> In Fire Safety Engineering there are many areas where a verification is important and valid.

[36] ABCB (2019) National Construction Code

> The built environment evolves quickly, and even building codes struggle to keep pace with the ever-changing construction industry.

5.2. THE ROLE OF THE IFEG

The positioning of the IFEG in the regulatory environment described above is more clearly as a guideline referenced in the building code. Like any other example of a best practice document, adherence to the IFEG can be neither policed nor enforced. Ultimately, Fire Safety Engineers are the ones responsible for practicing the discipline properly, and they may choose to do so with or without following the guidelines. They are also the ones trusted with safeguarding the profession and ensuring that certain minimum standards of quality and competency are maintained.

Even with updates, the technical content of the guidelines may not be enough to conduct a proper Fire Safety Engineering analysis. In this case, requiring strict adherence to the guidelines may be counterproductive, which would result in the creation of paths for exemptions that would defeat the purpose of the original regulation.

Incorporation of the current form of the IFEG into national or state policies would be difficult, if not impossible. However, there are portions of it that may be more amenable for implementation into regulations. Examples include the clear definition of acceptance criteria, the role of third-party reviews and standards for the preparation of the FER and FEB and a clear definition of who is a fire safety engineer, the knowledge, skills and attributes he or she must have, certification requirements, etc.

Regulation of the above listed items will help remove ambiguity in the discipline and provide a clear and traceable approach. Issues such as what constitutes an acceptance criterion should be avoided altogether and instead be replaced with a quantifiable level of performance. Provisions for the requirement of peer reviews may be used to ensure that a given solution is properly analysed or that projects with a high degree of complexity are evaluated by someone else besides designers and the approval officers.

One additional challenge with implementing the entirety of the IFEG into the building code is the long update cycle or lack of updates when compared to the regulatory environments. The built environment evolves quickly, and even building codes struggle to keep pace with the ever-changing construction industry. The international nature of the IFE Guidelines mean that any sort of revision requires a significant time and resources investment. To this date, only one version of the IFEG is suited for international application, and it is the one that has not been updated. When the guidelines were primarily developed for Australia, two versions where issued within five years. There have been no updates to the international version since its initial release. As an authority that references the IFEG in their regulations, the ABCB should support and promote the updating and revision of the IFEG.

5.3. THE ROLE OF PRACTICE GUIDES

According to the SFS, the Practice Guides (or Practice Notes) are tools that summarise the available equations, correlations and models for performing a certain type of analysis, along with data input requirements, data sources, details of the inherent assumptions and limitations of these correlations. Engineering practice guides often describe acceptable processes and procedures.

They are not referenced in the NCC/BCA, and thus could fall under the classification of guidelines, or arguably design or evaluation tools for fire safety engineering. Their definition as a design tool for fire safety engineering is arguably more appropriate, especially given the stated purpose of Practice Guides by the SFS. However even in this instance, it can be seen that the Practice Guides traverse the different components of the framework described herein, since for example the SFS Practice Guide for *Façade/External Wall Fire Safety Design*[37] includes a statement of Performance Requirements. Thus, parts of it clearly fall under the definition of a code. This situation is only acceptable if the performance requirement stated is consistently at least as onerous as those in the regulations. It must therefore be recognised and reinforced that only a code should contain the governing definition of Performance Requirements.

An important consideration that has not been a matter of discussion is the role of the SFPE Handbook for Fire Protection Engineering.[38] This document summarises the state of the art in all relevant domains of Fire Safety Engineering. Here there is clear and significant overlap between both the content and the intended function of the Practice Guides and the SFPE Handbook. The SFPE Handbook is updated in regular cycles of five to seven years and therefore provides current and relevant information.

Only a code should contain the governing definition of Performance Requirements.

[37] Practice Guide on Façade/External Wall Fire Safety Design, Society of Fire Safety Practice Guide, February 2019.
[38] SFPE Handbook for Fire Protection Engineering

Example of access & egress stairway in a heritage listed 150 year old building.

6. Conclusions

THE PURPOSE OF THIS REPORT HAS BEEN TO REVIEW THE BENEFIT AND UTILITY OF FSVM, IFEG AND PRACTICE GUIDES FOR FIRE SAFETY ENGINEERING.

AS PART OF THIS PROCESS HOWEVER, IT WAS DEEMED NECESSARY BY THE AUTHORS TO REVIEW THE DESIGN AND VERIFICATION PROCESSES THEMSELVES AND THE REGULATORY ENVIRONMENT IN WHICH THESE ARE APPLIED.

The design and verification processes are conceptually very different processes. However, this is not the case in fire safety engineering in Australia. The FSVM confuses DtS provisions with Performance Requirements. The DtS provisions are in fact tools for a designer to develop the specifications for a Fire Safety Strategy for a building that falls within the classifications described in the building code that permits such a solution. These are one example of many tools that should be available to an engineer working within a performance-based regulatory environment to facilitate the design process.

This confusion between the DtS provisions as a tool and as a performance requirement is dangerous since the DtS provisions have never been shown to result in a safe building when applied outside of the classifications of the code. In fact, the DtS provisions have never been shown to satisfy explicitly any specific performance objective since no explicit performance objective for a Fire Safety Strategy or the individual components of a Fire Safety Strategy have ever been defined. Further, this approach abstracts the overall objective of the Fire Safety Strategy into specifications for individual components. This means that partial solutions, comprising a combination of components of a DtS Solution and a Performance Solution, are never actually verified to provide an acceptable level of safety.

All of the above appears to be a symptom of the fact that the NCC in Australia is not a true performance-based code since it lacks a clear link between societal goals, functional objectives and Performance Requirements. This means that the value of the FSVM is diminished and in fact that the risk with their implementation is heightened since they promulgate the confusion of the DtS provisions as a performance requirement against which Performance Solutions can be verified. Further, the FSVM, as it exists today, is unnecessarily complicated and influences the design process.

> There is a clear difference between the design process and the separate verification process, and neither should interfere with the other.

The IFEG are deemed to fit well into a performance-based regulatory environment since they do not conflict with the building code or codes and describe a methodology for carrying out the fire safety engineering design process. However, while these are in principle of value in practice, they are known to be in need of updating.

The role of Practice Guides is far more straightforward since they represent what is collectively considered to be best practice by the profession. However, in the examples considered, they are found to confuse their role by stating Performance Requirements in some instances. While this may often represent an increased desired level of performance than the code, their subservience in relation to the codes must be reinforced.

Against the current background in Australia, this report makes three research findings that suggest fundamental building code and regulatory change is needed in Australia:

- There is a clear difference between the design process and the separate verification process, and neither should interfere with the other.
- The concept of equivalence to the DtS Provisions does not work as a concept or in practice.
- There is a need to quantify the Performance Requirements of the NCC.

Based on all of the above, the following recommendations are made:

1. That the Performance Requirements in the NCC/BCA be revisited and that the use of a DtS Solution as an evaluation tool for an acceptable level of safety be carefully reviewed. This must be done in such a way that Performance Requirements are traceable to societal goals and functional requirements.
2. That the adoption of partial DtS/ Performance Solutions through decomposition of the Fire Safety Strategy be prevented and that the holistic nature of the Fire Safety Strategy be reinforced.
3. That the FSVM be revised such that it respects the independence of the design process and that it adequately verifies that the Performance Requirements are met.
4. That the IFEG be updated or that they be removed from reference in future editions of the NCC/BCA.
5. That the purpose of Practice Guides issued by professional societies and others be clarified and that it be ensured that these remain outwardly compatible with existing articles of reference.

Governments and the Building Ministers Forum continue to struggle to find a way to respond to the façade issues and the Shergold/Weir Building Confidence recommendations.

7. Glossary of Terms

TERM	DEFINITIONS AND NOTES OF EXPLANATION Where definitions are included in the NCC Volume One Building Code of Australia, they are in **bold**. Other definitions or notes of explanation have been developed in this Warren Centre Project as a means to use consistent language throughout the Project reports.
ABCB	The Australian Building Codes Board (ABCB) is a Council of Australian Government (COAG) standards writing body that is responsible for the development of the NCC, comprised of the BCA and PCA. The ABCB is a joint initiative of all three levels of government in Australia. *(ABCB)*
Assessment Method	**Means a method that can be used for determining that a Performance Solution or Deemed-to-Satisfy Solution complies with the Performance Requirements.** *(NCC, vol 1, amdt 1)* The means by which a building proponent proves that a solution achieves the Performance Requirements. These include: • Evidence to support that the use of a material or product, form of construction or design meets a Performance Requirement or a Deemed-to-Satisfy Provision as described in A2.2 • Verification Methods • Expert Judgement • Comparison with the Deemed-to-Satisfy Provisions *(NCC, vol 1, amdt 1)*
Building Code of Australia (BCA)	Forms part of the National Construction Code, which contains technical provisions for the design and construction of buildings and other structures. The BCA addresses structural adequacy, fire resistance, access and egress, services and equipment, energy efficiency and sustainability, and provisions for the health and amenity of occupants. *(NCC, vol 1, amdt 1)*
Building Solution	**A solution which complies with the *Performance Requirements* and is a:** **• *Performance Solution*** **• *Deemed-to-Satisfy Solution*** **• *Combination of both solutions*** *(NCC, vol 1, amdt 1)* This term has been replaced with the terms Deemed-to-Satisfy Solution and Performance Solution. It has been retained as some jurisdictions still refer to this term. *(NCC, Guide, amdt 1)*
Deemed-to-Satisfy Provisions	Make up the bulk of the NCC. **Means provisions deemed to satisfy the *Performance Requirements*.** *(NCC, vol 1, amdt 1)*
Deemed-to-Satisfy (DTS) Solution	**A method of satisfying the *Deemed-to-Satisfy Provisions*.** *(NCC, vol 1, amdt 1)* Should be used if any designer, builder or the like, does not want to develop a new means of compliance with the Performance Requirements. *(NCC, Guide, amdt 1)*
Equivalent	**Equivalent to the level of health, safety and amenity provided by the *Deemed-to-Satisfy Provisions*.** *(NCC, vol 1, amdt 1)*
Fire Safety Engineer	An appropriately qualified and experienced practitioner who, through sound and robust engineer practice, provides services that achieve reductions of risk for life for people in buildings, reduction in property and environmental damage from building fires and the implementation of cost-effective fire safety codes and regulations.

Central Park apartment, Sydney.

TERM	DEFINITIONS AND NOTES OF EXPLANATION
Fire Safety System	**One or any combination of the methods used in a building to:** **• Warn people of an emergency** **• Provide for safe evacuation** **• Restrict the spread of fire** **• Extinguish a fire** **and includes both active and passive systems.** These systems may be active, passive or any combination of the two. **Active Systems** • Sound systems and intercom systems for emergency purposes • Emergency lighting • Exit signs • Sprinkler systems • Fire hydrant systems • Fire hose reel systems • Smoke and heat vents • Mechanical smoke-exhaust systems • Portable fire extinguishers **Passive Systems** • Fire-isolated stairways, ramps and passageways • Fire walls Other fire-resisting building elements *(NCC, Guide, amdt 1)*
National Construction Code (NCC)	The NCC provides the minimum necessary requirements for health, safety, amenity and sustainability in the design and construction of new buildings throughout Australia. It comprises of the BCA plus the PCA and is given legal effect by relevant legislation in each State and Territory. *(ABCB)*
Performance Requirement	**Means a requirement which states the level of performance which a Performance Solution or a Deemed-To-Satisfy Solution must meet**. *(NCC, vol 1, amdt 1)* Performance Requirements outline the levels of accomplishment different buildings must attain. There are three options to comply with the Performance Requirements: Deemed-to-Satisfy Solutions, Performance Solutions or a combination of both *(NCC, vol 1, amdt 1)*
Performance Solution (Alternative Solution)	**Means a method of complying with the Performance Requirements other than by a Deemed-To-Satisfy Solution**. *(NCC, vol 1, amdt 1)* A Performance Solution is unique for each individual situation. These solutions are often flexible in achieving the outcomes and encouraging innovative design and technology use. It is a route which is not included in a DTS Solution. It complies with the NCC when the Assessment Method demonstrates compliance with the Performance Requirements. If it is demonstrated to be at least equivalent to a DTS Provision, the Performance Solution is deemed to have achieved compliance with the relevant Performance Requirement. *(NCC, vol 1, amdt 1)*

8. Appendix 1

THE ABCB FIRE SAFETY VERIFICATION METHODS

It is intended to function as a methodology to be applied to a performance solution that allows the user to demonstrate that the proposed performance solution meets the performance requirements of the BCA.

8.1. WHAT ARE THEY?

The Fire Safety Verification Methods (FSVM) are one component of the NCC/BCA. It was introduced in the 2019 edition of the standard for adoption in 2020. It was developed by the ABCB with some input from various collaborators.

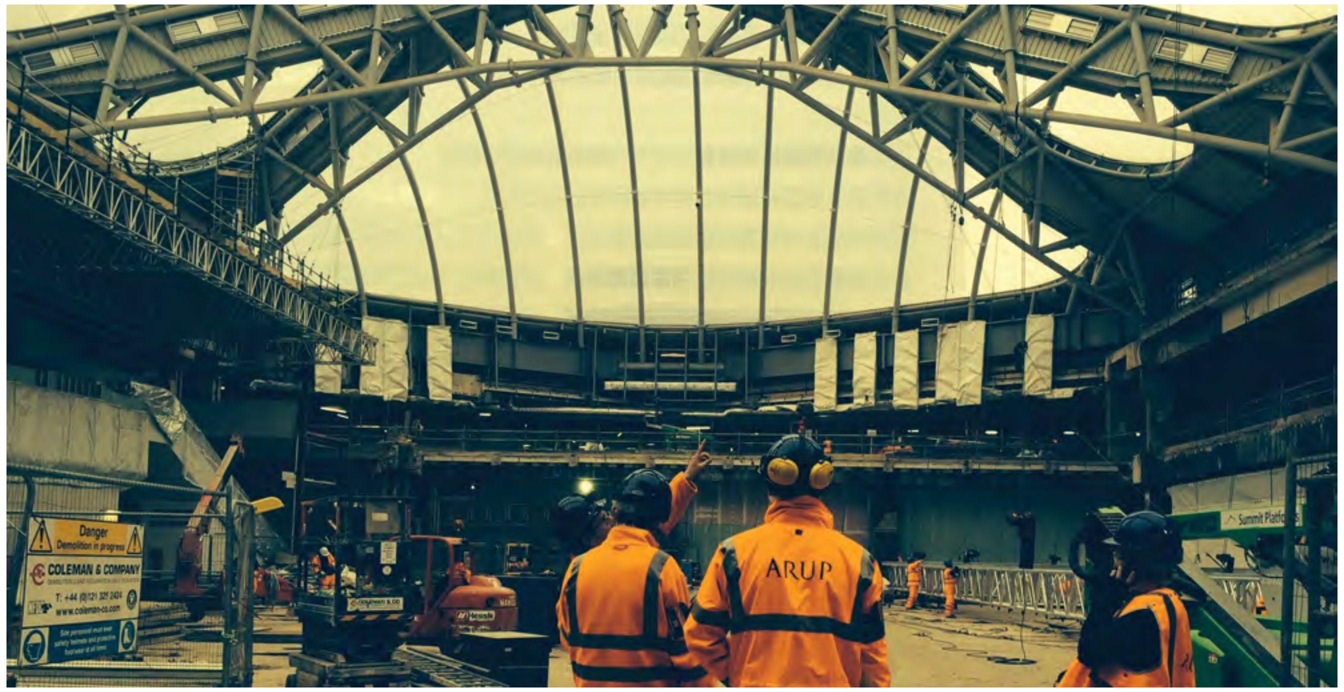
The NCC is split into mandatory documents and non-mandatory guides/handbooks. The mandatory guides include everything in the NCC including the Performance Requirements, DtS Provisions, Verification Methods, and the option for Performance Solutions to other methods, such as a first principles approach.

The FSVM is intended to be used by fire safety engineers that are competent and have an appropriate level of experience that would allow them to be accredited by a suitable body. It is intended to function as a methodology to be applied to a performance solution that allows the user to demonstrate that the proposed performance solution meets the performance requirements of the BCA. The FSVM is intended to provide a process for flexible Performance Solutions while still meeting the level of safety required by the BCA.

The earliest version of the FSVM reviewed by the authors of this report consisted of 12 qualitative scenarios and detailed quantitative inputs to be used including items such as fire sizes, travel speeds, and modelling rules, much like the Fire Safety Verification Methods in New Zealand, the NZ C/VM2. All scenarios and inputs were part of the 'mandatory' part of the document, i.e. part of the NCC itself and not the accompanying guide/handbook to the use of the FSVM.

The first revision of the FSVM made fully available to the public was the Public Draft Comment revision. This version contained the same 12 qualitative scenarios and inputs with some minor changes, along with a general restructuring of the document. The restructure results in the 12 qualitative scenarios being part of the 'mandatory' document and all of the quantitative inputs being moved to a non-mandatory guide which is referred to as the FSVM Handbook or simply the Handbook.

The final revision made available for this report, and the one upon which the comments in this report are based on, is the version of the FSVM and Handbook which was circulated in November 2018 to the Engineers Australia Society of Fire Safety (SFS) for review and comment. This is very close to the version which was ultimately adopted in the NCC/BCA 2019. This version of the FSVM contains only qualitative scenarios with acceptance criteria determined by the nearest available DtS solution specifications from the NCC/BCA. The accompanying Handbook is qualitative,



Site inspection from Fire Safety Engineers.

and the document details process and approaches but without detailed quantitative inputs. Each draft has had a similar intent/ goal as well as approach to verification.

The FSVM and Handbook are often referred to in this report as a single document item in this report, however it is worth noting that the FSVM is incorporated in the NCC whereas the Handbook is a guide to implementation of the methods.

As a result of the approach to verification, the FSVM are only suitable when the fire safety objectives being pursued as part of the design process are in line with the BCA Performance Requirements, fire hazards falling outside normally occurring events, i.e. storage of dangerous goods, chemical processing, business continuity, property protection, etc. could not be addressed via the FSVM.

The FSVM is not intended as a replacement of existing knowledge in the discipline and should therefore not be used by inexperienced (incompetent) persons as a substitute to a Fire Safety Engineer. This places restrictions on the users of the FSVM that are addressed and mandated on a state level by local regulations. This aspect has been discussed elsewhere in this Warren Centre Project.

The FSVM itself is a very brief document that comprises very high level 'how to use' and 'purpose' sections with a small section on process. The verification methods comprise 12 qualitative design scenarios against which a proposed performance solution should be tested, the result of which can be used to demonstrate compliance by comparison with the results of the nearest available DtS solution being tested against the same scenarios. Each of these design scenarios has a required outcome.

The handbook on the other hand is a much more detailed document that is over 100 pages in length. It is a qualitative document, but it is intended to be accompanied by detailed Data Sheets which as of the time of writing were yet to be fully developed.

Sections 1 through 8 of the handbook cover Application, scope, a summary of building regulations and NCC Compliance structure, Process/summary of developing a Fire Safety Strategy, a brief summary of reporting e.g. what goes within an FEB/ FER (referred to as a Performance Based Design Brief, PBDB or PBDR), and a Process to determine what scenarios are relevant.

Sections 9 to 12 detail the individual scenarios against which a design should be verified, as well as analysis methods with reference to ISO standards and risk assessment.

8.2. WHAT DO THEY TRY TO ACHIEVE?

The FSVM attempts to provide an approach to verification of performance-based design intended to be suitable to all buildings (as opposed to the new limitations on NZ C/ VM2). The overall approach to Verification is based on the comparison of a response of a proposed performance solution with the response of a DtS solution from the nearest available classification in the NCC. Verification that the objectives of the codes are achieved is possible if the performance solution has a level of safety that is at least equivalent to the DtS solution against which it is compared. However, the FSVM have not been thoroughly tested on performance-based designs, and it is therefore not possible to draw significant conclusions on whether this is achieved or not. Indeed, earlier versions of the FSVM were tested on DtS buildings and did not achieve this.

The FSVM Handbook identifies that Fire Safety Engineering must consider the life cycle of a building and be involved with all appropriate stakeholders.

As with some of the other documents reviewed in this report, the FSVM recognise that competence of the practitioner is a key requirement for their use. However, the FSVM do not define what level of competency is expected. Given inconsistencies between competencies expected of Fire Safety Engineers in the different states in Australia, there is no guarantee of consistency in implementation of the FSVM. Indeed, given that the FSVM nominate and describe a minimum number of scenarios against which a design has to be tested, there is no guarantee that competency will lead to the correct identification of appropriate additional scenarios. The intended implementation of the FSVM therefore relies on the competency of the engineer applying them, however a competent engineer will have no need for the FSVM.

9. Appendix 2

THE IFEG

9.1. WHAT ARE THEY?

The International Fire Safety Engineering Guidelines (IFEG) are a set of guidelines containing recommendations for the practice of fire safety engineering. These guidelines are applicable to any type of Fire Safety Engineering design process, including but not limited to new buildings, upgrades, etc.

Back in 1996, the Australian Building Codes Board (ABCB) released the first set of guidelines primarily intended for application in Australia. An updated version, but still focused in Australia was published in 2001. The current version of the guidelines was released in 2005, and it is the result of a joint effort between agencies from Australia, Canada, New Zealand and the United States of America. International collaboration resulted in a set of general guidelines suitable for the fire-safe design of buildings, as well as the building approvals process when appropriately used by properly qualified practitioners.

The guidelines represent the current knowledge of the discipline at the time of publication. Nonetheless, the guidelines also recognise that proper qualification and competency are key given the large amount of engineering judgement required in the practice of fire safety engineering. For this reason, the guidelines are not presented as a path to compliance but instead as a set of resources meant to aid the execution of fire safety engineering by:

- Linking the regulatory system and Fire Safety Engineering;
- Guiding the process of Fire Safety Engineering; and
- Providing guidance on methodologies and data available.

The IFE guidelines are broken into four parts. Part 0 provides background information and guidance necessary to understand the role of the IFE guidelines within a particular country. As such, there are four different versions of Part 0. The Australian version introduces the Australian regulatory system and the role of the IFE guidelines in the Fire Safety Engineering design and building approval process of alternative solutions for the Building Code of Australia (BCA). This part also presents background information about Fire Safety Engineering, its role in the life cycle of a building and the uniqueness of solutions based on building types, occupants' characteristics, etc. Part 0 makes a special emphasis on the qualifications of fire safety engineers and the need for accreditation.

> International collaboration resulted in a set of general guidelines suitable for the fire-safe design of buildings.

Part 1 sets out recommendations for assisting Fire Safety Engineers and other professionals in the Fire Safety Engineering process. Part 2 describes a selection of methodologies that may be used during the Fire Safety Engineering process. Part 3 provides data that may be used in support of the methodologies presented in Part 2, or other suitable methodologies. Parts 1 through 3 are provided as general recommendations and are not intended to be all-inclusive. The guidelines clearly recognise that there are additional methodologies and supporting data that may also be used as part of the Fire Safety Engineering process.

It is important to highlight that the IFEG are not a replacement for properly qualified fire safety engineers. Experience and competence are must haves in order to ensure proper application of the information contained in the IFEG. It is assumed that persons involved in the Fire Safety Engineering process are properly trained and qualified.

9.2. WHAT INFORMATION IS IN THEM?

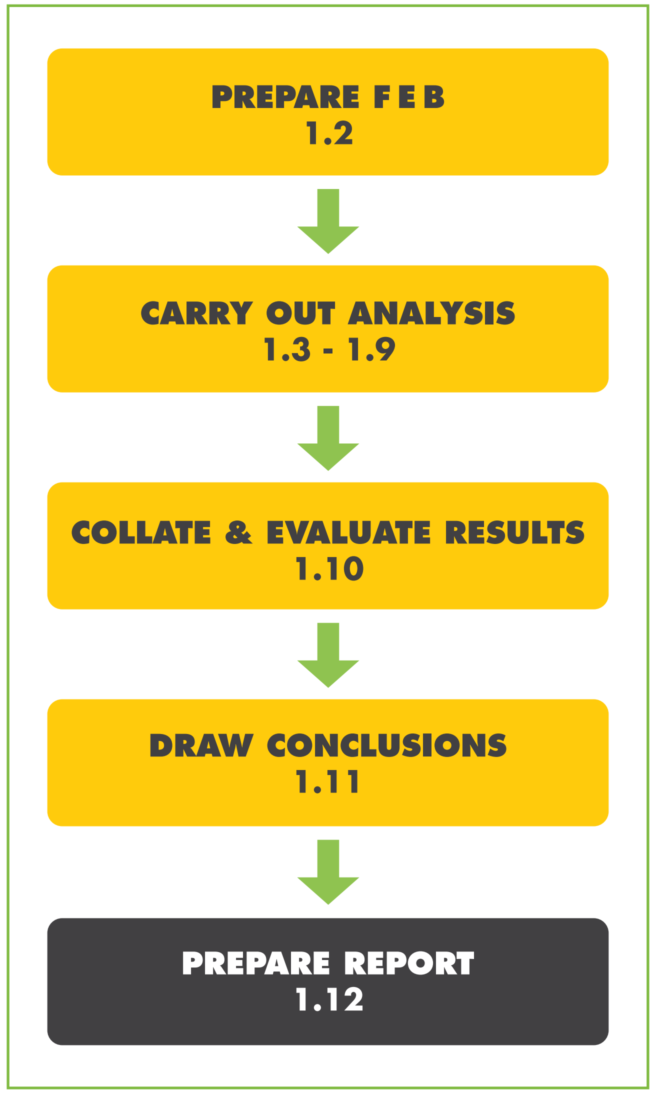


Figure 2: Typical fire engineering process

9.2.1. PART 1: THE FIRE SAFETY ENGINEERING PROCESS

The centrepiece of the IFEG is the definition of the Fire Safety Engineering process as shown in the figure 2 (left). A key aspect of the Fire Safety Engineering process is the formulation of the Fire Safety Engineering Brief (FEB). Part 1 identifies 13 unique steps for the formulation of the FEB. These steps are meant to capture the clear definition of the project among relevant stakeholders, definition of the building and occupant characteristics, objectives of the Fire Safety Strategy, hazard identification and measures available, trial design assessment, identification of non-compliance issues, definition of approaches, analysis methods, fire scenarios, and acceptance criteria. Examples are provided for each category.

Later sections of Part 1 detail the considerations for conducting the analysis of the trial design. At this point, the Fire Safety Strategy is broken into sub-systems that allow evaluating the fire safety systems of a building.

The IFE guidelines identify six subsystems as follows:

- Subsystem A: Fire initiation, development, and control
- Subsystem B: Smoke development, spread, and control
- Subsystem C: Fire spread, impact, and control
- Subsystem D: Fire detection, warning, and suppression
- Subsystem E: Occupant evacuation and control
- Subsystem F: Fire service intervention

The subsystems to be evaluated will depend on the nature of the non-compliance issues, specific and/or performance objectives, interactions between subsystems and the nature of the approaches and methods used. In order to facilitate evaluation of a particular subsystem, the guidelines introduce a sequence of chronological events consisting of:

- Scope: What aspects of the subsystem are to be analysed
- Procedure: How will the subsystem be used
- Output: What output information is expected out of the analysis
- Input: What information is required and where it can be found
- Analysis: How will the analysis be performed
- Construction, commissioning, management and use: Important issues relating to such categories are important to consider
- Bibliography: List of any references used in the analysis

According to the guidelines, the analysis process consists of eight unique steps that may involve an iterative process. Step 1 is analysis of the trial design based on the FEB. Step 2 is identification of non-compliance issues. Step 3 is determination of the specific objectives/performance requirements. Step 4 is selection of the approach and analysis method. Step 5 is the actual analysis including sensitivity and uncertainty analyses. Step 6 consists of collating and evaluating results. Step 7 evaluates the conclusions of the analysis and determines whether the outcomes are acceptable or whether further iterations are required. Step 8 is the final step concluding in the formulation of a Fire Safety Engineering Report (FER). A recommended format for the FER alongside with details for each section is presented as part of the guidelines.

9.2.2. PART 2: METHODOLOGIES

This section provides detailed guidelines, methodologies for the different portions of the Fire Safety Engineering process identified in Part 1. These recommendations are

meant to capture accepted methodologies, and the use of alternative ones is also deemed acceptable. This Part contains equations, methodologies, etc. that are meant to aid engineers in performing the necessary analysis. The approaches are similar to those contained in the SFPE Handbook, NFPA standards, technical document, and research publications.

9.2.3. PART 3: DATA

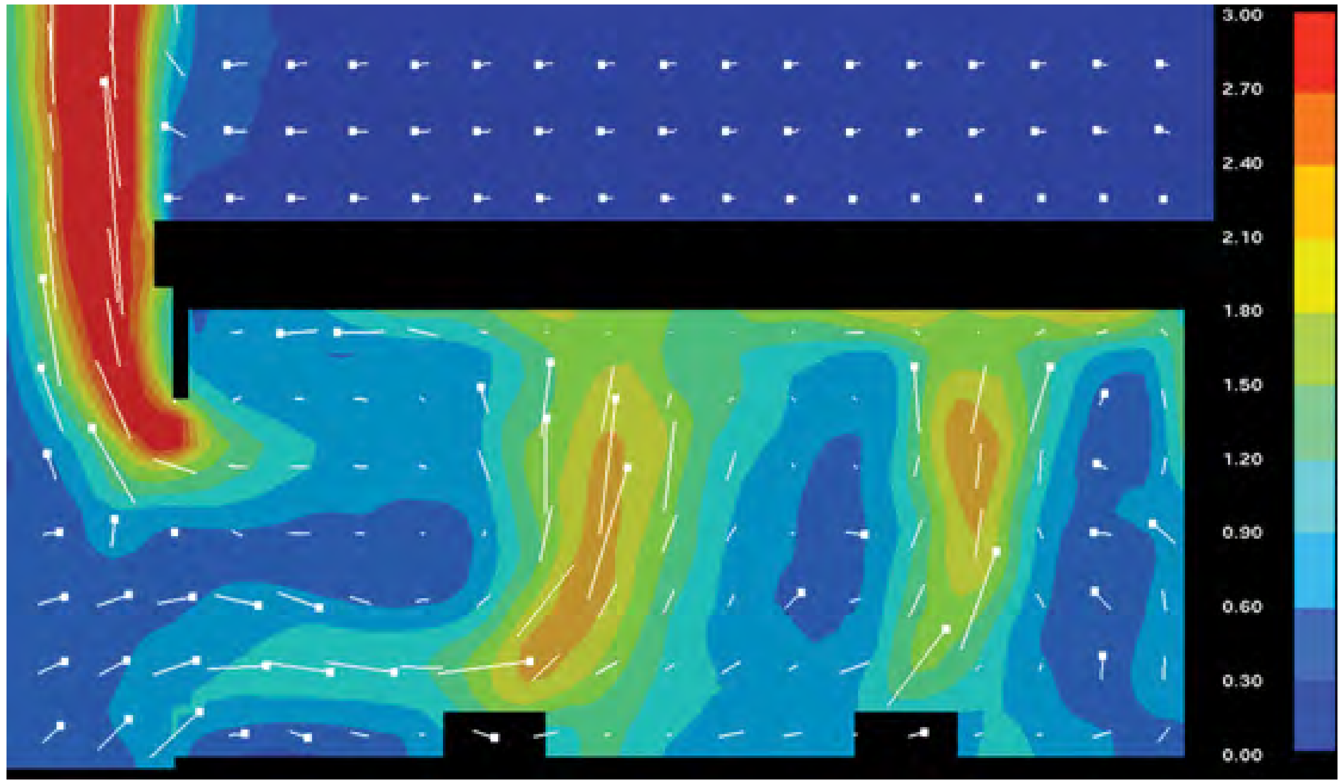
This section contains data that can be used in the development of Part 2. Careful application of the data is recommended given differences in regulations, construction practices, rapid evolution of the built environment, etc. The data is provided in order to match the different subsystems identified in Part 1.

9.3. WHAT DO THEY ACHIEVE?

The main contribution of the IFEG is the collection of best practices within fire safety engineering at the time of its publication. Even though the guidelines are dated, and Fire Safety Engineering has evolved noticeably since 2005, portions of the approaches and methods presented in the guidelines remain applicable. For example, FERs, FEBs are routinely used by Fire Safety Engineers in both design and approvals roles. However, the degree to which all of the guidelines are followed cannot be accurately assessed.

Part 1 of the IFEG highlights the role of Fire Safety Engineers throughout the design and approval process. This section highlights the value added from properly engaging Fire Safety Engineers and developing a consensus among the multiple stakeholders. To that end, the guidelines reflect an aspiration on the part of the authors of the IFEG of what Fire Safety Engineering should be while setting a guiding framework for the practice of Fire Safety Engineering across multiple jurisdictions and ranges of occupancies.

Part 2 of the guidelines provide a common ground for the assessment of the different subsystems identified in Part 1. The risk with the methodologies presented in Part 2 is the incorrect application of said methodologies by incompetent Fire Safety Engineers. This risk is clearly identified in the scope of the guidelines, but realistically there is no way of enforcing that only properly qualified engineers have access to the guidelines. It could be argued that despite the benefits they present, the IFEG give individuals with a limited background in Fire Safety Engineering a path to mistakenly overcome their lack of knowledge or experience.



A plot from FDS. It shows an analysis of flows in and out of a compartment with two burners on the floor. It is plotted using FDS v6.6.0. Image courtesy of University of Queensland Fire Safety Engineering Research Group.

The guidelines may not necessarily capture the state of the art of the discipline nor address issues raised since 2005.

The guidelines do not contain any information that a properly qualified Fire Safety Engineer may have not encountered before. Furthermore, it is likely that said engineers may have had to use alternative methodologies with a higher complexity than the ones presented in the guidelines. In that sense, the analysis methodologies presented in Parts 2 and 3 are no different from information that can be found in resources such as the SFPE Handbook of Fire Protection Engineering or scientific publications. However contrary to the references mentioned above, the IFEG does not elaborate on the assumptions, discussions and limitations of the approaches presented.

Given that the last update occurred in 2005, and given the substantial evolution of the discipline, the guidelines may not necessarily capture the state of the art of the discipline nor address issues raised since 2005. Since the publication of the IFEG, the SFPE Handbook of Fire Protection Engineering has been updated twice, in 2008 and 2016, and at the time of writing is undergoing a further update. In the same period, Australia's National Construction Code has been updated four times: 2011, 2015, 2016 and 2019.

In summary, the guidelines achieve some centralisation of information and provide a clear picture of the role of fire safety engineering in the built environment. The technical information contained in them can lead to oversimplification of the discipline by neglecting proper discussions of the assumptions and/or limitations of the methodologies and data presented. The lack of a recent update means that the guidelines in their current form may not represent state of the art of Fire Safety Engineering and may be inadequately suited to address current and future challenges in Fire Safety Engineering.

9.4. INCORPORATING THE IFE GUIDELINES INTO REGULATIONS

Like any other examples of best practice documents, adherence to the IFEG cannot be policed or enforced. Ultimately, Fire Safety Engineers are the ones responsible for practicing the discipline properly, and they may choose to do so with or without following the guidelines. They are also the ones trusted with safeguarding the profession and ensuring that certain minimum standards of quality and competency are maintained.

Even with updates, the technical content of the guidelines may not be enough to conduct a proper Fire Safety Engineering analysis.

Newcastle Rail Interchange. Transport for New South Wales (TNSW) define verification as the "process performed to ensure that the output of a design stage or stages meets the design stage input requirements".

In this case, requiring strict adherence to the guidelines may be counterproductive, which would result in the creation of paths for exemptions that would defeat the purpose of the original regulation.

Incorporation of the current form of the IFEG into national or state policies would be difficult, if not impossible. However, there are portions of it that may be more amenable for implementation into regulations. Examples include the clear definition of acceptance criteria, the role of third-party reviews and standards for the preparation of the FER and FEB and a clear definition of who is a Fire Safety Engineer, the skills he or she must have, certification requirements, etc. Regulation of the above listed items will help remove ambiguity in the discipline and provide a clear and traceable approach. Issues such as what constitutes an acceptance criterion would be avoided altogether and instead replaced with a quantifiable level of performance. Provisions for the requirement of third-party revisions may be used to ensure that a given solution is properly analysed or that projects with a high degree of complexity are evaluated by someone else besides designers and the approval officers.

One additional challenge with implementing the entirety of the IFEG into building regulations is the long update cycle or lack of updates when compared to the regulatory environments in which it is used. The built environment evolves quickly, and even building codes struggle to keep pace with the ever-changing construction industry. The international nature of the IFEG means that any sort of revision requires a significant investment of resources and time. To this date, only one version of the IFEG is suited for international application, and it is the one that has not been updated. When the guidelines were primarily developed for Australia, two versions were issued within five years. There have been no updates to the international version since its initial release.

10. Appendix 3

PRACTICE GUIDES

Within the scope of this section, a set of available Practice Guides and Practice Notes used in Australia (Australian or international) are described. An attempt is made herein to analyse and describe:

- the stated objective of Practice Guide;
- how is its relevance assured;
- what does it achieve; and
- how best to incorporate the Practice Guide within the current design and regulatory framework.

10.1. SFPE HANDBOOK FOR FIRE PROTECTION ENGINEERING

This international handbook provides a thorough description of the current fundamental knowledge in fire safety engineering and science. It is of more than 3,500 pages. The fifth version of the SFPE Handbook received input from 130 practicing Fire Safety Engineers and researchers, representing universities and professional organisations around the world.

The relevance of the SFPE Handbook is assured by periodic updates in regular cycles of five to seven years. It therefore provides current and relevant information. This handbook is reviewed by the corresponding editors of the document.

The SFPE Handbook gathers an incredibly diverse range of fire safety related fundamentals: fire dynamics, hazard calculations, human behaviour, fire risk analysis, structural behaviour in fire, etc. This allows for a single source of reference to almost all areas related to fire safety engineering and science.

The SFPE Handbook does not indicate any type of Performance Requirement; hence, enforcement of it is not relevant. Given the large amount of information in this handbook, its correct use is influenced by the competency of the engineer in implementing design tools and making use of data presented in the Handbook, within the context of his or her regulatory environment.

10.2. SFS PRACTICE GUIDES

The objective of the SFS Practice Guides is to describe acceptable fire safety engineering processes and procedures. The SFS Practice Guides are documents that summarise equations, correlations and models that may be used for performing a certain type of engineering analysis. These documents may also describe and show data required, refer to data sources, and explain inherent assumptions and limitations.

The task group of SFS members develop a draft Practice Guide utilising related available research publications and solicit input from organisations and individuals that possess the required expertise. Once a draft of the Practice Guide has received approval of the task group, an email public notice to SFS members will invite comment from the membership. The SFS Executive committee will review the Practice Guide for consistency in meeting SFS goals and adherence to policies and bylaws. If appropriate, the task group will review and revise the guide on a regular basis and reissue it with a new date. The process for this is not clearly stated in the Development Procedures document for SFS Practice Guides.

The SFS Practice Guides are documents that react to a specific area identified by the SFS membership as having a lack of engineering guidance within the Australian context. In this environment, Practice Guides are developed in response to an identified need and are rapidly adopted by practicing engineers. Thus time-frames between draft and adoption of an SFS Practice Guide can be very short.

The best way to incorporate the use of SFS Practice Guides is assuring that its content is constrained to engineering tools and data, with no statement made on Performance Requirements, and only reference provided to the corresponding code.

10.3. LOCAL GOVERNMENTS' GUIDES AND PRACTICE NOTES

A suite of Practice Guides and Notes which outline the standards for development in priority development areas (PDAs) have been prepared by the Queensland government. The Victorian government practice notes provides guidance to engineering practitioners on certain topics related fire safety. For example, the Victorian government recently released amendments to the requirements for automatic fire suppression systems and other fire safety measures in existing residential care and shared accommodation buildings as a result of the introduction of Building Regulations 2018 (VIC).

Proposals for new Practice Guides (or proposed amendment to existing practice guides) can be submitted by any practitioner in any type of organisation. This allows for a continuous relevance check on behalf of Australian practicing engineers. The process of approval and review of these documents is not clearly explained in available information.

These Practice Guides and Notes provide tools which are reactive to gaps only identified by local practicing engineers. Hence, they fulfil gaps perceived by the practicing community only. The quality of these documents is only reflected by the competence of practicing engineers in identifying engineering gaps and producing such documents. As with SFS Practice Guides, local governments' Practice Guides and Notes may sometimes include statements of Performance Requirements, thus falling under the definition of a code.

The best way to incorporate the use of local governments' Practice Guides and Notes is to assure that their content is constrained to engineering tools and data.

Interior View of Drafting Room in ERB, courtesy of NASA Commons.

11. Appendix 4

EXAMPLES OF PERFORMANCE REQUIREMENTS FROM OTHER JURISDICTIONS

This appendix contains some examples of performance requirements as worded in different jurisdictions. These are taken from the ABCB NCC 2019[39]; the Building regulations in both Scotland[40] and England[41]; as well as the Building Code in New Zealand.[42] Regulations in England are the subject of increased scrutiny as a result of, e.g. The Hackitt report,[43] and in Scotland a review of the Scottish Building Standards Agency's Technical Handbooks was recently undertaken.[44] New Zealand has an FSVM similar in function to the ABCB's FSVM.

Examples are presented for the requirements related to "structural stability" for each of these jurisdictions. Note that all jurisdictions have a vagueness or ambiguity about the performance requirement which precludes verification against the requirement alone.

11.1. AUSTRALIA

CP1 of Volume 1 of the NCC 2019 states that:

A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to—

a) the function or use of the building; and
b) the fire load; and
c) thepotentialfireintensity;and
d) the fire hazard; and
e) the height of thebuilding; and
f) its proximity to other property; and
g) any active fire safety systems installed in the building; and
h) the size of any fire compartment; and
i) fire brigade intervention; and
j) other elements they support; and
k) theevacuationtime.

11.2. THE UNITED KINGDOM

11.2.1.ENGLAND

Requirement B3 of Part B to Schedule 1 of the Building regulations states that:

(1) the building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.

(2) A wall common to two or more buildings shall be designed and constructed so that it adequately resists the spread of fire between those buildings. For the purposes of this sub-paragraph a house in a terrace and a semi-detached house are to be treated as a separate building.

(3) Where reasonably necessary to inhibit the spread of fire within the building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following:

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[39] ABCB (2019) National Construction Code
[40] The Building (Scotland) Regulations 2004
[41] The Building Regulations 2000
[42] Ministry of business, innovation and employment (2014) New Zealand Building Code Handbook
[43] Hackitt, J (2018) Building a Safer Future Independent Review of Building Regulations and Fire Safety: Final Report
[44] Stollard, Paul (2018) Report of the Review Panel on Building Standards (Fire Safety) in Scotland

(a) sub-division of the building with fire-resistance construction;
(b) installation of suitable automatic fire suppression systems.

(4) The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited.

The corresponding DtS solution for this requirement is described in Approved Document B.

11.2.2. SCOTLAND

Requirement 2.3 of Section 5 of the The Building (Scotland) Regulations 2004 states that:

Every building must be designed and constructed in such a way that in the event of an outbreak of fire within the building, the load-bearing capacity of the building will continue to function until all occupants have escaped, or been assisted to escape, from the building and any fire containment measures have been initiated.

The corresponding DtS solution for this requirement is described in the SBSA Technical Handbooks.

11.3. NEW ZEALAND

The New Zealand code includes both Functional Requirements and statements of Performance, for Structural Stability these comprise:

FUNCTIONAL REQUIREMENT

C6.1 Structural systems in buildings must be constructed to maintain structural stability during fire so that there is:

a) a low probability of injury or illness to occupants,

b) a low probability of injury or illness to fire service personnel during rescue and firefighting operations, and

c) a low probability of direct or consequential damage to adjacent household units or other property.

PERFORMANCE

C6.2 Structural systems in buildings that are necessary for structural stability in fire must be designed and constructed so that they remain stable during fire and after fire when required to protect other property taking into account:

a) the fire severity,

b) any automatic fire sprinkler systems within the buildings,

c) any other active fire safety systems that affect the fire severity and its impact on structural stability, and

d) the likelihood and consequence of failure of any fire safety systems that affect the fire severity and its impact on structural stability.

C6.3 Structural systems in buildings that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after fire.

C6.4 Collapse of building elements that have lesser fire resistance must not cause the consequential collapse of elements that are required to have a higher fire resistance.

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