Urban design and wildfire engineering at the wildland-urban interface: a review of international urban planning and building requirements

Peer reviewed

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SUBMITTED
3 December 2023

ACCEPTED
2 February 2024

DOI
www.doi.org/10.47389/39.4.53

Abstract

It has been almost a decade since Gonzalez-Mathiesen and March (2014) completed their international analysis that identified 9 design features for wildfire risk reduction via urban planning. Despite their recommendations and subsequent global attempts to enhance and improve resilience from an urban design perspective, wildfires[1] remain one of the costliest hazards globally, both from a financial and a human perspective. This continued devastation raises the question as to whether urban design and wildfire engineering practices have either been adopted or changed since Gonzalez-Mathiesen and March (2014). To consider this, this paper presents a review and comparison of contemporary international wildland-urban-interface-related urban design legislation, policy and frameworks. Inconsistent approaches to addressing wildfire-related risk, and at times competing standards required between planning and building approaches were identified. These only serve to further reduce the potential effectiveness of measures intended to improve wildfire resilience at the national and international scales. Future work should focus on establishing evidence-based performance standards that emphasise the practical application of the findings of the best available current research to be incorporated into planning and construction. At the same time, it may be necessary to review policy approaches to clearly align key definitions of tolerable risk as well as provide clarification about how performance standards can be demonstrated.

Introduction

In recent years, large and severe wildfires have increased in occurrence, duration and intensity (Jolly et al. 2015). Recent mega-fires provide evidence of their scale and effects (Filkov et al. 2020; Lie and Banerjee 2021; Bonilla-Aldana et al. 2019). As part of the efforts to increase community preparedness for and resilience to wildfire, international jurisdictions have adopted guiding principles (ABCB 2014, 2022a, 2022b; WAPC 2023; QFES 2019; NFPA 2013) and prescriptive codes and standards (Miller et al. 2016; SAI Global 2018; NFPA 2017) that apply to both urban planning and fire engineering design of buildings within the wildland-urban interface (WUI) (also known as the rural-urban interface, or RUI). In addition, common urban planning design elements across jurisdictions (e.g. asset protection zones, road access standards, firefighting water access and enhanced construction standards) attempt to reduce the effects of wildfire and to assist fire services successfully defend life, property and the environment (NFPA 2013). Collectively, these requirements aim to increase the preparedness of communities to withstand wildfire, which is an essential component of the emergency management model of prevention, preparedness, response and recovery.

It has been almost a decade since Gonzalez-Mathiesen and March (2014) completed an international analysis that identified 9 design features for bushfire risk reduction via urban planning. These principles (summarised in Table 1) aimed to either reduce

1. The term 'bushfire' is used in Australia and 'wildfire' is used in other countries. Wildfire and its plural are used throughout this paper and are synonymous with other terminology such as 'wildland fire' and 'bushfire'.

Table 1: Nine design principles for bushfire risk reduction via urban planning.

Reducing vulnerability	Coordinating and improving response
Consideration of the overall context and landscape impacts on exposure from overall fire likely behaviour.	Consideration of the availability, capacity, location and travel times of emergency services, if available.
Determination of adequate separation from heat and flame sources, given topography, vegetation, likely weather and any other relevant factors.	Facilitation of the efficient access and egress of emergency services, including integration of separation spaces as spaces for active defence or evacuation locations.
Management or modification of vegetation, landscaping or other fuel sources such as outbuildings.	Ensure water availability for firefighting, including appropriate location, supply, connectivity and signage.
Management of the density, location, and design of structures, including reducing vulnerability to ember attack, and integration of building and planning standards appropriate to context and siting.	Deal with civilian response actions, including the range of possible actions such as finding refuge, actively defending or evacuating properties.
Protection of infrastructure, and care for land uses with greater vulnerability, for example, kindergartens.	

Source: Gonzalez-Mathiesen and March (2014)

community vulnerability (largely relying on the physical design of a settlement) or to improve firefighting and emergency response. Despite these findings and subsequent global attempts to enhance wildfire resilience (Intini et al. 2020; Penney and Richardson 2019; Penney et al. 2020a; Syphard et al. 2013, 2017), wildfires continue to be among the costliest disaster events both from a financial and a human perspective (Intini et al. 2020; Penney et al. 2019a; Blanchi et al. 2012; Cova et al. 2011; Haynes et al. 2008). Such destruction leads to the question as to whether urban design and wildfire engineering practices have been adopted or have changed since the work by Gonzalez-Mathiesen and March (2014). This study addresses this question with a review and comparison of contemporary international WUI-related urban design legislation, policy and frameworks. This study is significant in that it provides a contemporary review of international urban design and wildfire engineering guidelines, extends the breadth of international WUI building and planning requirements and provides a review of strategic governance, regulatory and engineering approaches that Gonzalez-Mathiesen and March (2014) considered as being required. Applications of the findings of this study facilitate improved practice in each of the themes examined, provides a basis to assist future research and contributes to the literature exploring wildfire engineering and increased resilience.

International planning and building approaches

Australia

In Australia, bushfire-resistant construction standards are incorporated into the National Construction Code via the Building Code of Australia through the adoption of Australian Standard AS 3959:2018 Construction of Buildings in Bushfire-Prone Areas (SAI Global 2018) (referred to as AS 3959). The applicability of AS 3959 is triggered by the identification of land being susceptible to bushfire or being 'bushfire-prone'. This identification essentially captures all land within 100 metres from the development containing vegetation greater than one hectare[2] in area, could burn (Penney et al. 2020a). AS 3959 details the methodology to calculate radiant heat flux as a result of worse-case fire on structures and provides associated Deem-to-Satisfy[3] and limited performance-based enhanced construction standards to increase the resilience of structures.

Notwithstanding several important technical limitations as described in Penney and Richardson (2019); Penney et al. (2020a), the use of AS 3959 has extended into jurisdictional planning provisions (WAPC 2021; NSWRFS 2019; Tasmanian Government 2020; DPCD 2011; State of Queensland 2019; Victorian Government 2024) as a method for determining whether land use is appropriate from bushfire exposure. Design requirements for urban development in areas prone to bushfire vary between jurisdictions, however, they ultimately focus on 4 aspects:

- Location as determined by a hazard level known as the Bushfire Attack Level (BAL), which is derived from the worst-case calculated radiant heat flux in accordance with AS 3959.
- Asset Protection Zone as being the separation area between flammable vegetation and the structures to be protected.
- Access and egress that includes road construction standards, access design considerations and fire service access routes.
- Firefighting water sources.

2. A hectare is 10,000 metres^2 or 0.01 kilometres^2.

3. Deemed-to-Satisfy provisions are the required design factors, materials, components and construction methods that, if used, meet the performance requirements of the associated code or policy. Performance-based solutions (also known as performance solutions) don't follow the 'recipe' of Deemed-to-Satisfy and provide an equivalent or higher level of safety measured against the performance requirement.

Table 2 summarises these requirements as well as some of the design limitations identified in this study.

While various bushfire planning provisions provide limited consideration for performance-based solutions, there is a dearth of quantitative performance requirements and verification methods identified and an almost total reliance on the approval authority's qualitative assessment (Penney et al. 2020a) of proposed performance-based alternative solutions. In comparison, since the adoption of the 2022 version of the Building Code of Australia in 2023, there are now quantified probabilistic performance requirements that apply to construction in bushfire-prone areas. There is also considerable variation between jurisdictions within Australia, with some states (including Victoria) enforcing bushfire requirements in joint planning and construction legislation, while other states such as Western Australia and New South Wales rely on separate planning legislation and construction legislation. Combined with the current state of bushfire engineering practice being unregulated (in other words, no certification or license is required to practice), the result can be inappropriate design decisions leading to inappropriate development, difficulty in enforcing compliance, excessive land use restriction, costly over-engineering and development delays (Penney and Richardson 2019). The design requirements also fail to directly consider firefighter tenability or operational feasibility limits (Penney et al. 2019a, 2019b, 2020a, 2020b, 2020c).

Canada

Bénichou et al. (2021) provides a significant and recent contribution to urban design and life safety guidance for developments in wildfire-prone areas. In this Canadian guide, an introductory explanation of wildfire fuels and behaviour is provided as well as a comprehensive

Table 2: Summary of urban design bushfire considerations and identified limitations across Australia.

Category	Requirement	Limitations
Location	Development appropriate in areas subject to radiant heat flux not greater than 29kW/m^2 (BAL-29) with high-risk or vulnerable land use not permitted in areas exceeding 12.5kW/m^2 (BAL-12.5). Development conditional on construction standards in accordance with AS 3959. Developments classified as either vulnerable land use (for example schools, hospitals and aged care facilities) or hazardous land use (industrial developments) are subject to additional measures that vary between jurisdictions. Typically, lower radiant heat thresholds (10kW/m^2) are tolerated from a planning perspective while additional performance-based solutions are required under the Building Code of Australia for Class 9 development (equivalent to vulnerable land use classification under planning approaches).	AS 3959 provides deemed-to-satisfy construction standards for developments exposed to a radiant heat flux greater than 40kW/m^2, however, from a planning perspective, only developments facing a maximum 29kW/m^2 are considered inappropriate. This creates conflict between planning and building codes and guidelines. Planning guidelines still rely on active firefighting intervention but do not consider human tenability and firefighter operational effectiveness thresholds are less than 3kW/m^2 (Penney et al. 2019a), Construction in accordance with AS 3959 is a deemed-to-satisfy approach in the Building Code of Australia meaning that irrespective of actual BAL rating, if AS 3959 is followed, the safety and risk standards of the Building Code are deemed to have been met. Building Code provisions introduced in May 2023 provide additional performance requirements with few deemed-to-satisfy provisions and approved verification methods for Class 9 buildings (health care, assembly and residential-care buildings). If correctly approached, the fire safety design of the development can address these requirements through a single approach. Conversely, if planning and building approaches are siloed and independent of each other, the potential for costly and lengthy disputes to resolve conflicts is a real possibility.
Asset Protection Zone	Landscape to include a defendable space that ensures a maximum radiant heat flux of 29kW/m^2 on the structure and is designed as an area for firefighters to conduct wildfire suppression operations. In most jurisdictions, the asset protection zone must be retained entirely within the individual land parcel, preventing adjoining properties combining to satisfy the Asset Protection Zone requirements.	
Access and egress	The primary requirement is for 2 different access routes connecting to a public road network and providing 2 different destinations. It also details design standards for internal road networks and fire service access routes.	Some major points are not considered: • Position of egress routes in relation to bushfire. • Urban density and road usage. • Time required to safely evacuate vs. available time until fire arrives (known as RSET vs. ASET).
Firefighting water supply	Requires either a reticulated or water tank supply. Where water tank supply is used, a nominal volume of water is typically required (e.g. one 50,000L tank per 25 lots or one 10,000L tank for lots greater than 500m^2).	Some major points are not considered: • Whether fire suppression operations are possible on the site. • Firefighting water flow rates and volumes required are based on credible worst-case scenarios for the sites in question.

Source: Information is summarised from WAPC (2021), NSWRFS (2019), Tasmanian Government (2020), State of Queensland (2019) and Government of South Australia (2020).

summary of National Fire Protection Association codes and research from Canada and the United States. Capturing a combination of hazard assessment criteria and methodologies, in addition to qualitative and prescriptive design standards in a similar fashion to those in the Australian Building Code and planning guides, the *National guide for wildland-urban-interface fires* (Bénichou et al. 2021) stops short of providing fire engineering approaches, verification methodologies or performance-based solutions. Bénichou et al. (2021) provide additional commentary and guidance for community utilities, public transportation and firefighting response qualifications, capabilities and legislative powers.

United States

Increasing the resilience of urban design at the WUI remains a priority for large areas within the United States. California is often perceived and portrayed as having the greatest risk due to wildland fire, with recent research (Mowery and Punchard 2021) reporting '32% of all housing units are in the WUI'. This has had a devastating effect in the event of wildfire. Conditions influencing fire behaviour (e.g. fuel, weather and topography) along with public policy, including land use, have created a history of destructive fires and has led to the development of building codes and a culture of reducing the effects of the next disaster.

The focus on resilience ranges from fire codes, building codes and reference standards, to public resources, government codes and operating principles for firefighters. In California, this is developed and implemented across numerous agencies from the state's executive and legislative branches through several agencies including the Department of General Services and Department of Forestry to local jurisdictions including cities and towns. The California Fire Code Chapter 49 *Requirements for Wildland-Urban Fire Interface Areas* (2022) covers the mitigation of conditions where wildfire burning in vegetative fuels may affect the built environment (e.g. ignite buildings, pose a threat to life, overwhelm suppression or result in large property losses).

The Director of the California Department of Forestry is empowered to classify lands and establish a Fire Hazard Severity Zone (FHSZ) that considers wildfire history, updated fuels data and potential hazard to the built environment. The California Building Code Chapter 7A *Materials and Construction Methods for Exterior Wildfire Exposure* (2019) specifies the types of building materials and construction methods that should be used for construction within the WUI. These requirements apply to all (moderate, high and very high) FHSZ areas in state responsibility and (currently) in very high FHSZs of local responsibility.

The California Building Code has numerous sections that each address building components and often have multiple prescriptive options for complying with the requirements. Within the California Fire Code, statutes, codes and regulations address road standards for fire equipment access and standards for identifying streets, roads and buildings. Defensible space requirements (analogous to Asset Protection Zone in Australia) are given for 2 zones, 0–30 feet (0–9 metres) and 30–100 feet (9–30 metres), with recent legislative changes acknowledging the importance of the 0–5 feet (0–2 metres) sub zone to be ember resistant.

Firefighters and emergency responders come from a multitude of organisations including local, state, and federal resources (volunteer and professional). The state firefighting resource, CAL FIRE, publishes a document on operating principles for the WUI incidents (CDFFP 2014).

Table 3 is a summary of the FHSZ, defensible space, access and egress and firefighting water supply considerations in California.

Beyond California, wildfire considerations for urban design vary across state and local jurisdictions (Mowery and Punchard 2021). Colorado has a large and growing population within the WUI but has few requirements in terms of land use (new developments) and lacks adoption of statewide building codes for wildfire hazards. Some states like Montana and Washington have taken steps to addressing WUI design considerations through regulation and offer tools for local jurisdictions to use and adopt. Some states and local jurisdictions have adopted the *International Wildland-Urban Interface Code* (ICCI 2020). Additionally, the National Fire Protection Association publishes consensus standards NFPA 1140: Standard on Wildland Fire Protection and NFPA 1142: *Standard on Water Supplies for Suburban and Rural Firefighting* that may be referenced by other codes.

New Zealand

In contrast to both Australia, Canada and the United States, the community perception in New Zealand is that wildfires are not prevalent enough to need planning. The prevailing view is represented in Kornakova and Glavovic (2018):

> *Most people in New Zealand are not prepared at all. People are very prepared for earthquakes and tsunamis and volcanic activity, but I don't think most people would have thought about fire as a threat. People have always seen it as something that happens in Australia or California or parts of the Mediterranean basin, and not something we need to worry about so much.*
> (Kornakova and Glavovic 2018)

In the absence of designated wildfire planning or construction requirements, Fire and Emergency New Zealand (FENZ) offers guidance to rural property owners on its website, including a rural property checklist (FENZ 2021a) and guidance on landscaping for fire safety (FENZ

Table 3: Summary of wildfire considerations for urban design in California.

Category	Requirement	Limitation
Fire Hazard Severity Zone	Considers wildfire history, fuel loading, slope, weather and other relevant factors including areas where winds have been identified as a major cause of wildfire spread.	For local responsibility areas, maps are only published by the state for very high FHSZ.
Defensible space	Fuel modification and maintenance in a condition so that a wildfire burning under average weather conditions would be unlikely to ignite the structure.	Depending on lot size and setback distances, the 5–30 feet (2–9 metres) zone may be on a neighbour's property.
Access and egress	Roads and driveways that provide for safe access for firefighting equipment and civilian evacuation concurrently.	Fails to consider: • Position of egress routes in relation to wildfire. • Urban density and road usage. • Time required to safely evacuate vs. available time until fire arrives.
Firefighting water supply	Emergency water is available, accessible and maintained in quantities and locations to attack a wildfire or defend property.	Fails to consider: • Whether fire suppression operations are possible on the site. • Firefighting water flow rates and volumes required are based on credible worst-case scenarios for the sites in question.

Source: California Fire Code (2022)

2021b). The checklist introduces the concept of creating a safety zone around rural dwellings consisting of an inner and outer zone. It is suggested the inner zone (0–10 metres from the home) consists of lawn and fire-resistant plants and trees, while the outer zone (10–30 metres from the home) includes removal of scrub and thinning existing trees, even spacing of remaining trees so that the foliage is not touching that of adjacent trees, pruning of large trees and removal of all branches within 2 metres of the ground, removal of dead or dying trees and the removal of overhanging trees near power lines. No other fire-based urban design requirements are considered.

Other countries

In France, the Forest Fire Risk Prevention Plan (Cerema 2022) relies on physical separation between 50–200 metres of buildings from vegetation that could burn. Applying a similar approach, Spain relies on 50 metres separation between vegetation and dwellings in certain areas as well as the provision of dedicated firefighting water sources (Xunta de Galicia 2007; Junta de Extremadura 2006). In contrast, neither Portugal nor Chile mandate any specific urban design or construction provisions to address the threat of wildfire. However, recent research suggests that such approaches are required (Castillo Soto et al. 2022; Samora-Arvela et al. 2023).

Discussion

While there is evidence of the 9 design principles established by Gonzalez-Mathiesen and March (2014) being partially applied in contemporary urban design and wildfire engineering requirements, the acceptance of enhanced resilience measures into urban design solutions remains varied. Australia adopts the strictest governance model from a building perspective, embedding construction standards through Standard AS 3959 being identified as a deemed-to-satisfy solution to the performance criteria of enhanced construction standards required in bushfire-prone areas. The Standard also requires WUI measures within state- and territory-specific legislation. However, the Australian regulatory mechanism for application of urban design planning requirements varies between states and territories, which may lead to irregular application. Critically, none of the Australian planning guidelines or policies reviewed referenced evidence to support design criteria beyond the qualitative principles set by Gonzalez-Mathiesen and March (2014) and few referenced verification methods beyond the calculation of radiant heat using AS 3959.

A similar situation exists within the United States, with California adopting a stricter approach to enforcing urban design requirements at the WUI compared to Colorado, Montana or Washington. Canada and New Zealand are less strict in the application of construction and urban design provisions and provide guiding (non-mandatory) provisions only. Spain, Chile and Portugal provide little, if any, risk mitigation measures to be applied. While this situation might be considered reasonable in New Zealand due to its perceived low risk of WUI fires occurring, this is not the case in Canada, Spain, Chile and Portugal, which all have a significant history of wildfire events.

The combined planning, building, fire service and community environment is a complex system with competing elements. It is challenging to identify competition across different elements and the introduction of an apparent solution in one area can result in suboptimal outcomes in another area. For example, the requirement to have specified exit routes (one of the original 9 principles) without consideration for traffic density, traffic flow rates, fire behaviours or safe evacuation times could lead people to be overrun by the fire front while trying to evacuate. When considered alongside the ongoing destruction caused by wildfires, these findings suggest that urban design and wildfire engineering at the WUI needs significant improvement. The solution lies in the adoption of formal fire engineering approaches like those already adopted within the built environment for fire safety within the Building Code of Australia, inclusive of defined performance criteria and verification methods that facilitate an evidence-based approach to urban design as opposed to the largely qualitative judgement approaches currently applied globally.

Conclusions

This paper presented a review of contemporary international WUI-related urban design legislation, policy and frameworks with a comparison to original work by Gonzalez-Mathiesen and March (2014). This study extended the breadth of international WUI building and planning requirements and reviewed strategic governance, regulatory and engineering approaches that Gonzalez-Mathiesen and March (2014) deemed as being required.

We found that the acceptance of enhanced wildfire resilience measures into urban design solutions remains varied globally. The inconsistent approaches to wildfire-related risk and, at times, competing standards required between planning and building approaches serves to further reduce the potential effectiveness of measures intended to improve resilience at a national and international scale. While there is a requirement for increased adoption of appropriate governance frameworks and regulation in areas subject to wildfire, there is also a need for robust research to develop evidence-based urban design solutions.

Ultimately, attempting to solve the wildfire issue through isolated planning and building solutions will be ineffective and result in unnecessary financial costs and bureaucratic processes. Future work should focus on the establishing evidence-based performance standards emphasising the practical application research into the combined planning and construction approach to the wildfire problem. It may be necessary to reconsider policy approaches to more clearly align key definitions of tolerable risk, as well as providing clarification as to how performance standards can be demonstrated.

Disclaimer

All statements expressed in this article are those of the authors and do not necessarily reflect the official opinion nor policies of their affiliated institutions, civilian, military, government or other.

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