



Guidance on Design and Construction of the Built Environment Against Wildland Urban Interface Fire Hazard: A Review

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Abstract. Wildland-Urban Interface (WUI) fires, a worldwide problem, are gaining more importance over time due to climate change and increased urbanization in WUI areas. Some jurisdictions have provided standards, codes and guidelines, which may greatly help planning, prevention and protection against wildfires. This work presents a wide systematic review of standards, codes and guidelines for the design and construction of the built environment against WUI fire hazard from North American, European, Oceanic countries, alongside with trans-national codes. The main information reviewed includes: the definition of WUI hazards, risk areas and related severity classes, the influence of land and environmental factors, the requirements for building materials, constructions, utilities, fire protection measures and road access. Some common threads among the documents reviewed have been highlighted. They include similar attempts at: (a) defining WUI risk areas and severity classes, (b) considering land factors including the defensible space (also known as ignition zones), (c) prescribing requirements for buildings and access. The main gaps highlighted in the existing standards/guidelines include lacks of detailed and widespread requirements for resources, fire protection measures, and lacks of taking into account environmental factors in detail. The main design and construction principles contained in the reviewed documents are largely based on previous research and/or good practices. Hence, the main contributions of this paper consist in: (a) systematically disseminate these guidance concepts, (b) setting a potential basis for the development of standards/guidelines in other jurisdictions lacking dedicated WUI fire design guidance, (c) highlighting gaps in existing standards/guidelines to be addressed by current and future research.

Keywords: Wildland-Urban Interface, WUI, Wildfire, Design guidance, Standard, Fire

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1. Introduction

Fires in the Wildland-Urban Interface (WUI) have become a global issue, with recent disasters taking place in a number of places, including Europe, North/South America and Oceania [29]. A wildland fire is defined as an: “*unplanned and uncontrolled fire spreading through vegetative fuels, at times involving structures*” [32]. If it develops in a wildfire-prone boundary between structures and vegetation, than it can be considered as a Wildland Urbane Interface (WUI) fire [30].

The WUI fire issue may get worse in the future, due to climate change [27] and population growth in the WUI areas [36]. In fact, the current situation may evolve towards more dangerous scenarios in areas which have already experienced a long history of fires, such as the USA, Canada, Australia, Southern Europe, etc. [43]. However, other regions which have been not traditionally subject to wildfires may become more vulnerable in future years, due to climate change and modifications in the location and wildfire intensity, such as South America, Africa and Northern Europe [27]. Thus, the phenomenon of fires in WUI areas should be considered from a broad international perspective.

For example, in Canada, the number of wildfire evacuations per year has increased by 1.5% from 1980 to 2014, with more than 20 evacuations per year after 2010. The 2016 Fort McMurray fire alone had the costliest impact in the Canadian history in terms of insured losses [43]. Due to these urgent needs, research has started to address the consequences of these incidents [8, 30], provide measures to aid evacuation planning [9], and coupling fire, traffic and pedestrian models to aid response to such incidents [25, 42, 43].

The development (and continuous revision) of standards and guidelines can be crucial in reducing the negative impacts of WUI fires on communities involved through appropriate dedicated measures and design guidance. Some countries have already developed standards and codes concerning measures for response planning, prevention, protection, fighting, etc. of WUI fires. Other jurisdictions can rely on guidelines and local provisions, or on provisions which cover the issue of WUI fires, but are included in other general codes (e.g., Building Codes, Environmental Codes, Fire Codes, etc.). An International Code for WUI fires is also currently available [24]. On the other hand, there are other countries which do not have similar regulatory tools (and which do not adopt international provisions) and design guidance, even if they are already affected (or they may be affected in the future) by WUI fires.

The development (or revision) of standard/guidelines for design considering WUI fire-related issues may be eased by a broad knowledge of the current regional, national and trans-national design concepts, mainly based on previous research in this field and/or good practices. For this reason, the main objective of this work was to review provisions and guidelines available worldwide concerning WUI fires. This included both documents specifically focused on WUI fires as well as selected documents which are relevant to WUI fires, but are not explicitly dedicated to them. The document analysis has been done considering mainly countries with Subarctic, Mediterranean and Oceanic climate.

The final objectives of this paper involve: (1) highlighting the main commonalities in the documents reviewed, and (2) highlighting the main deficiencies. In fact, the identification of the common threads through the different provisions and guidance reviewed may be useful for researchers and practitioners who intend to develop or revise WUI-based standards and guidelines. In addition, highlighting deficiencies in standards and guidelines could shed some light on which part of research should be transferred into regulations or, eventually, if future research is needed on some specific topics.

2. Methods for the Review

In this section, the main documents reviewed and the methods used for conducting the review are explained in detail, by focusing on the structure and type of information which have been retrieved from the considered documents.

The documents reviewed relate to areas in North America, Europe and Oceania. They were selected given that they had proneness to fires in the WUI similar to the Canadian environment, considering similarities in industrial development, environmental and social conditions. Clearly, the European Mediterranean area could have been specifically targeted for the review of documents given it is prone to WUI fires (i.e., the Iberian peninsula, France, Italy, the Balkan peninsula, see Modugno et al. [31]). Two examples of countries among those most vulnerable were then considered for the review; namely, Italy and France. The language knowledge (English, French, Italian) of the authors was also taken into account in the selection of the reviewed documents. Two trans-national regulations were also considered: International WUI Code and EU Regulations.

The documents reviewed are listed and classified according to the geographic area to which they belong. Moreover, other reference sources and relevant documents considered during the review process are also identified. This information is summarized in Table 1. In this table, groups of documents are defined (e.g., US Standards, Italian Standards/Guidelines). These definitions are henceforth used throughout the remainder of the paper.

The following methodology was used to review the standards and guidelines regarding construction in areas deemed vulnerable to WUI fires. Relevant provisions and/or guidelines for WUI fires were collected from the reviewed documents according to a common template. The information collected is structured in three categorical levels:

- A macro-category (from A to G);
- A second-level sub-category;
- A third-level sub-category.

This approach was adopted to ensure a consistent representation of the provisions reviewed. The macro-categories and the second- and third-level sub-categories considered are reported and explained as follows. Moreover, they are graphically summarized in Fig. 1.

Table 1
Summary of the Documents Reviewed Classified According to the Country/Area of Reference, and Information Concerning Their Type, Main Content and Jurisdiction Level

Country/ Area	General regulatory conditions	Documents reviewed	Type of document (Jurisdiction) ¹	Definition of groups of documents	Notes/other referenced documents
Canada	No WUI fire-related standards. Guidelines descending from community programs	FireSmart Guidebook for Community Protection (Alberta Government) [1]	G (S/L)	Canadian guidelines	Includes most of the guidance provided in (FireSmart, 2003, 2017), and some guidelines provided in [44]
United States	WUI fire-relevant Standards, Federal/State Guidelines, local programs and guidelines	NFPA 1141 (2017) NFPA 1142 (2017) NFPA 1143. (2016) NFPA 1144 (2013) California Fire Code, Chapter 49: Requirements for Wildland-Urban Interface Fire Areas [46] Implementation Guidelines for Executive Order 13,728 WUI Federal Risk Management [34] Firewise toolkit [16] Colorado WUI Hazard Assessment Methodology [12] Wildfire Hazard Assessment Guide for Florida Homeowners [17]	S (C) S (S) S (C) G (C) G (S) G (S)	US Standards Californian Standards/ Guidelines US Guidelines	Example of application of the FireSmart country-level program to the local level Include provisions regarding WUI fire prevention, protection, mitigation, suppression, hazard definition, and required resources Reference to other NFPA Standards Includes references to other regulations (e.g. [7], [46]), guidelines (e.g., [45]) Provides minimum acceptable standards for US Federal buildings in risky WUI areas, complying with IWUIC [24] Provides guidelines to the general public Provides a specific methodology for WUI hazard and risk assessment Provides guidelines to the general public on different wildfire safety measures, and a methodology for wildfire hazard and risk assessment Provides guidelines about planning and protection measures
		The Planning for Natural Hazards: Wildfire Technical Resource Guide [35]	G (S)		

**Table 1
continued**

Country/ Area	General regulatory conditions	Documents reviewed	Type of document (Jurisdiction) ¹	Definition of groups of documents	Notes/other referenced documents
Australia	Standard for buildings in WUI areas, State guidelines	Construction of buildings in bushfire-prone areas [3]	S (C)	Australian standards/guidelines	Includes provisions related to WUI fires prevention, protection, mitigation, suppression, hazard definition, and required resources. Several other Australian standards and scientific research articles referenced in the text Provides guidelines for vegetation, resources, fire protection measures and access
New Zealand	No WUI-fire related standards. Parts of fire codes relevant for WUI fires	Guidelines of the States of South Australia [21] and Tasmania [22] Fire Emergency New Zealand Act (Fire and Emergency New Zealand [15]) New Zealand Building Code, Extract: Clauses C1-C6, A3 [11] (Fire and Emergency New Zealand [15])	G (S) S (C)	New Zealand and Standards/Guidelines	Codes regulating the protection of buildings and the surrounding areas from wildfires, relevant for the WUI fire case too
France	No WUI fire-related standards. Parts of the forest code relevant for WUI fires	New Zealand Building Code, Extract: Clauses C1-C6, A3 [11] (Fire and Emergency New Zealand [15]) Code Forestier (Republique Francaise) [18] Plans de prevention des risques naturels (PPR). Risques d'incendies de foret. Guide methodologique [37]	G (C) S (C) G (C/L)	French Standards/Guidelines	Provides guidelines concerning fire safety in rural homes Includes provisions concerning the plans required for different risky areas [13], including those related to fire risk Provides guidelines on which features should be included in the local plans for preventing predictable fires (PPRIF). [37] is an example of application of the PPRIF to the local level (highly exposed to wildfires)
		Arrete n. 2013071-2002, Département de la Haute-Corse [10]	G (L)		Provides guidelines concerning vegetation clearing in a WUI-prone region

Table 1
continued

Country/ Area	General regulatory con- ditions	Documents reviewed	Type of document (Jurisdiction) ¹	Definition of groups of documents	Notes/other referenced documents
Italy	No WUI fire-related standards. Parts of the fire code relevant for WUI fires	“Legge quadro in materia di incendi boschivi” (Framework law concerning wildfires), L. 21.11.2000, n. 353 (Repubblica Italiana) [41] Raccomandazioni per un più efficace contrasto agli incendi boschivi, di interfaccia e ai rischi conseguenti. Allegato [38] Piano Regionale per la Prevenzione, Prevenzione e Lotta attiva contro gli incendi boschivi [40], Prevenzione antincendi boschivi [5]	S (C) S (C) G (L)	Italian Standards/ Guidelines	Provides regulations concerning forecasting, preventing and fighting of wildfires Includes explicit reference to Wildland-Urban Interface fires Define regional planning activities with respect to wildfires, explicitly referencing interface fires, and including a framework for defining danger zones with respect to structures
World	Presence of a WUI fire-related standard	International Wildland-Urban Interface Code [24]	S (I)	International Standards	Defines the fire safety provisions to be adopted in the WUI area, including references to other International Codes (e.g., Building and Fire Codes)
Europe	No WUI-fire related standards. Regulations concerning forest fires	Council Regulation (EEC) No 2158/92 of 23 July 1992 [13] EC 2152/2003 (Forest Focus) [14]	S (I)	European Standards	Provide directives for the Member States mainly concerning the definition of hazard zones and protection plans concerning forest fires, do not explicitly mention WUI fires

¹S = Standard/Code/Regulation (henceforth referred to as “standards”), G = Guidelines/Recommendations (henceforth referred to as “guidelines”), (I) = applicable at the international level, (C) = applicable at the country-level, (S) = applicable at the State-level, (L) = applicable at the regional/local level

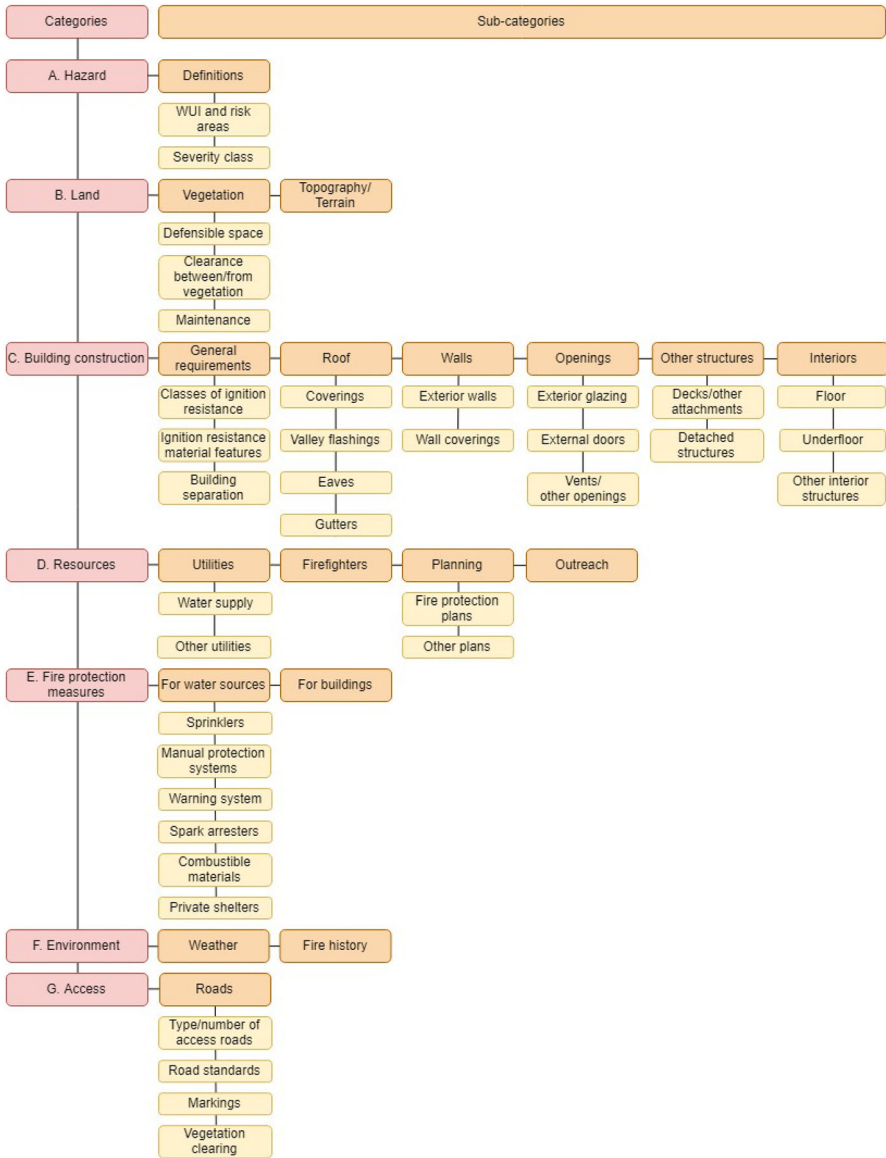


Figure 1. Summary of the categories taken into account for the consistent review of the information contained in the selected documents. Macrocategories are on the left (named from "A" to "G"). Second level sub-categories within each macro-categories are connected on the right (e.g. Land has sub-categories of Vegetation and Topography). The third-level sub-categories are reported below each relevant second-level category (in a lighter colour than the second-level categories). For instance, Vegetation includes Defensible Space, amongst other examples.

The macro-category “Hazard” relates to how hazard and risk zones are identified and classified. In particular the definition of WUI (Wildland-Urban Interface) and risk zones, alongside with the procedures used for identifying hazards and circumscribing zones, are reviewed. The procedures to define the different risk severity classes, and the thresholds delimiting the different risk categories are reviewed as well.

The macro-category “Land” relates to the measures adopted for the vegetation surrounding structures in terms of: (1) creating a defensible space (i.e. fuel modification: removal, reduction, substitution) and undertaking specific operations at given distances from the structures, (2) respecting given clearances between vegetation and other vegetation types/structures (or other objects); (3) undertaking maintenance procedures for the defensible space or the vegetation around structures. Moreover, the procedures that influence the terrain (i.e., slopes) and topography on the risk classification are reviewed as well.

The macro-category “Building construction” includes several elements. It includes the review of the general requirements for buildings and building materials with respect to fire safety: classes of ignition resistance, characteristics required for ignition resistance of building materials or part of structures, and clearance between buildings. It also includes the review of requirements for the specific elements: roofs (and the different parts composing them), walls (and other external coverings), openings (such as exterior glazing, external doors, vents and other openings), other structures (decks and other attachments, detachments), interiors (floors, under-floors and other structures).

The macro-category “Resources” includes several elements. It includes the review of the requirements for: (1) water supply (concerning the minimum supply level, the standby power, the location and size of hydrants in case of fire suppression), and other fire-safety related utilities; (2) firefighters, including procedures and activities before and during the emergency; (3) plans to be adopted for fire protection purposes (fire protection plans) and other plans relevant to WUI fire safety (e.g., emergency or development plans). Moreover, it describes the outcomes and general public (outreach) to which documents are dedicated.

The macro-category “Fire protection measures” includes the review of the requirements for water sources to use in fire protections and for buildings. Among protection measures for buildings, those adopted for sprinklers, manual protection systems in/near structures (e.g., fire extinguishers), warning systems (e.g., fire alarms), spark arresters (such as for chimneys), combustible materials and their distance from structures if allowed (e.g., debris, tanks, gases), private shelters against wildfires, are reviewed.

The macro-category “Environment” relates to how weather and fire history influence the measures or procedures to be adopted.

Finally, the macro-category “Access” relates to the fire safety requirements of the road access to structures. It includes the type and/or number of access roads required in the risk areas, the requirements concerning road standards (geometry, materials, parking lots, dedicated lanes) for main access roads and driveways/dead-end roads, markings (on access roads/streets and dwellings markers), and vegetation clearing operations to be conducted within the road limits.

3. General WUI-Relevant Information for the Areas Considered

Information relevant to WUI fires for the geographical areas considered are reported below in Fig. 2. This information concerns temperature and rainfall, climate, population, vegetation (forest types). They are important for considering the context in which different standards and guidelines are developed and used. Information relevant for WUI fires are not reported for standards corresponding to transnational areas, such as International or EU, since this information is not location specific. Information concerning temperature, rainfall, climate, population and vegetation may be useful while developing novel standards/guidelines, since the latter should be defined according to the local characteristics of the area under consideration.

- The extent of the Wildland-Urban Interface in the areas considered, together with additional information about fires and other relevant issues, are reported

	Canada	United States	Australia	New Zealand	France	Italy		
Average monthly temperature (°C)	Max.	11.3 (July)	20.1 (July)	27.8 (January)	14.7 (February)	18.7 (July)	20.8 (July)	
	min.	-24.3 (January)	-5.9 (January)	14.0 (July)	4.3 (July)	3.7 (January)	3.4 (January)	
Average monthly rainfall (mm)	Max.	58.4 (July)	66.0 (July)	78.2 (January)	160.0 (October)	81.2 (July)	108.6 (November)	
	min.	23.0 (February)	42.8 (February)	45.4	114.0 (February)	59.1 (February)	55.6 (July)	
Climate	main	Subarctic	-	-	Oceanic	Oceanic	-	
	others	Warm summer humid continental oceanic others	Humid subtropical/continental mediterranean semi-arid, desert	Mediterranean, cold semi-arid, hot/cold desert	Hot desert, savanna, oceanic, subtropical, mediterranean	Mountainous, mediterranean	Hot/warm summer mediterranean, humid subtropical, oceanic, tundra/warm summer humid continental	
Population (million inhab.)	>35	>320	>39	>24	>4	>67	>60	
Density (inhab./sq. km)	3.9	32.9	92.6	2.8	17.5	98.8	201.3	
Forest types	main	Temperate continental, boreal coniferous	Subtropical, temperate continental	Subtropical forest	Tropical, dry/shrubland, temperate oceanic, subtropical humid, tropical rainforest	Subtropical humid, temperate oceanic	Temperate oceanic, continental, subtropical	Subtropical dry, temperate oceanic
	others	Oceanic	Temperate oceanic	Temperate oceanic	Subtropical dry	-	-	-

Figure 2. Summary of the information relevant to WUI fires for the geographical areas considered. Specific data sources: Climate Change Knowledge Portal (1901–2015) for temperatures and rainfall, <http://www.fao.org/forestry/fra/80298/en> for forest types, Köppen scale for climate. Notes *Annual mean daily (1997–2014), **average monthly rain volume (1961–1990) (US Census/US Geological Survey).

as well. Since, in this case, a common world database with data of equivalent and refinement does not exist, the data used derived from local sources. In fact, although general definitions of WUI areas may be provided, different buffers between structures/infrastructures and the vegetation, or different percentages of built areas may be used for precise definitions of the WUI area. For example, Modugno et al. (2016) highlight that the definition of WUI area is standardized in the USA (built areas with < 50% vegetation, lying within 2.4 km of an area with at least 75% wildland vegetation, and at least 5 km² wide, as reported by [39]), based on [20]. In contrast, in some European countries the definition of WUI areas are not standardized (or they may vary between countries). Thus, comparisons between countries may be difficult without taking into account the local legal frameworks. For instance:

- *Canada* WUI area: 32.3 million ha (5.8% of the territory), largest WUI areas in Quebec (about 6.9 million ha), highest WUI percentages among the total State in Nova Scotia (45.1%) [26]. 5780 fires/year and > 1 million ha burnt by wild-fires (10-years average, 2017); with most of the fires/year (811) and largest area burnt/year (> 163 k ha) in Alberta.
- *USA* 46 million homes in the WUI area (2012), estimated conversion rate from wildlands to WUI: about 810,000 ha/year since 1990, 8 million projected new homes in next 10 years [23]. 89,000 ha designated by State foresters as at WUI fire high-risk, with about 100,000 wildfires burning 2.8 million ha/year, and 2970 homes/year lost on average since 2000 [23];
California: WUI area estimated in 746,037 ha, estimated number of houses in the WUI area: > 5 million [47]. Average area burned/year by wildfires (period: 2011–2015): 1272 km² (US Department of Agriculture, Forest Service).
- *Australia* More than 11,000 houses lost in Australia in the period 1939–2007; with most of the houses lost in the Victoria State (more than 60% of losses) [4].
- *New Zealand* National average annual total area burned in the period 1991–2007: 5865 ha, average number of wildfires increased from 1200 to 4000 annually in the same period, with the north islands accounting for two-thirds of all the wildfires, and grass fires accounting for the majority of area burned (54%) [2].
- *France* WUI area particularly present in some areas (e.g., in Bouches-du-Rhône: > 15% of the Department, 47% of fires starting in the WUI). About 4000 fires/year, 5.5 million ha of forests potentially exposed to fire risk, but a limited State portion severely attacked by fires (e.g., in Provence-Alpes-Cote d'Azur: 7000 burnt ha/year) [19]; MeteoFrance).
- *Italy* In the first seven months of 2017, 74,965 ha burned. The highest amount of ha. burnt were in the Regions: Sicily, Calabria and Campania [28].

4. Comparative Analysis of the Results from the Review

A comparative analysis of the information collected from the different sources is conducted here, by highlighting variability in key aspects of standards/guidelines under consideration. The comparative analysis is conducted separately for each

macro category, by focusing on the various approaches adopted by different guidance/regulatory provisions. Moreover, for each macro-category (see Fig. 1), a general comment is provided at the beginning of the sub-section, and more detailed comparisons provided for each second-level sub-category, where present (i.e., for land, building construction, resources, fire protection measures, environment).

4.1. Hazard

A definition of risk and hazard zones and the hazard classification are provided in all the standards/guidelines reviewed. Specific details concerning the hazard classification in the documents reviewed are provided in Table 2.

Definitions of wildfire risk and hazard levels are present in all groups of documents reviewed, except for the New Zealand group. The definition of specific risk areas is essentially based on some topographic, vegetation and environmental factors and should be made by the relevant authority. For example, the US standards base the definition of wildfire risk areas on characteristics such as: fuels, fire weather, defensible space, terrain, building construction and water supply, while the Australian standards define the wildfire risk for structures based on surrounding vegetation, heat flux exposure, predicted bushfire attack/exposure. The definition itself of WUI area is slightly different between different standards. In Australia, those areas are referred to as Bushfire-prone areas, and the wildfire risk level is defined as Bushfire Attack Level (BAL). Methods for identifying and classifying severity in the interface areas have been found in all the standards/guidelines reviewed, with different levels of detail. In the more detailed provisions/guidelines, the severity class is assigned based on a rating obtained as a sum of partial ratings related to different factors (e.g., in Canadian, US, Australian, and International documents reviewed). The main factors on which the total severity rating is obtained are: type of building construction and materials (i.e., roofs, exterior structures), vegetation (including distance from vegetation), fuels, slopes, critical fire weather frequency (the latter in the IWUIC, 2015). In the EU Guidelines, it is essentially based on geographic considerations based on fire history. Specific high-risk zones are identified in this way: Portugal, Spain, Greece, some regions of France and Italy. Risk assessments should be constantly conducted for these.

4.2. Land

Provisions/recommendations about the influence of land characteristics on the measures and procedures to be adopted in wildfire-prone areas are provided in all the groups of documents reviewed, except for the European Standards.

4.2.1. Vegetation The feature “vegetation” includes the quantitative and qualitative provisions for creating the defensible space, the clearance between different vegetation types (i.e., between tree crowns and between tree crowns and ground vegetation) and between vegetation and structures/infrastructures (i.e., buildings, power lines), and for maintaining vegetation around structures. Even with different quantitative provisions, the concept of defensible space is present in all the

Table 2
Comparative Summary Between the Standards/Guidelines Reviewed, Classified According to the Relative Jurisdictions

Jurisdiction/ Type of provision and public	Type of Hazard Definition	Buffer zone (vegetation)	Influence of terrain?	Prescriptions for structural elements (list)	Prescriptions for utilities
Canada (in- cluding Canadian provinces) Guidelines, dedicated to both commu- nities and homeowners	Four different ranges of hazard for structures, sites, and surrounding areas	Three priority zones with respect to vegetation management (priority 1: < 10 m, priority 2: 10–30 m, priority 3: > 30 m). Mandatory fuel removal in the priority zone 1. Recommended removal, reduction and species conversion in the other zones	Factors addressed: Slopes. Some guidelines for the relative position building/slope: building at least 10 m beyond the crest of the slope, or on the bottom of the hill. Severe fuel modification on slopes (especially > 10%)	Roof (including covering and eaves), exterior walls, glazing, openings, attachments. Guidelines not much detailed. Minimum separation between structures considered	Water sources (qualitative) and fire hydrants
United States Standards	Structures classified into five classes of occupancy hazard and construction types, with respect to wildfire risk, based on a detailed structure assessment	Mitigation measures for buildings located ≤ 30 feet (9 m) from vegetated slopes. Non-combustible barrier in case of scarce space between structures and vegetation. Fuel modification provisions to be included in fire mitigation plans	Factors addressed: slopes, topographical factors (flat areas, ridges, saddles, natural chimneys, canyons). Topography and terrain included in the structure wildfire risk assessment	Roofs (covering, eaves, gutters), exterior walls, exterior glazing and doors, openings, attachments and detachments. Specific provisions for building separation and ignition resistant materials	Water supply level (specific guidance on the minimum water supply), depending on the occupancy hazard, construction type, dimensions and exposures. Other provisions for water sources, access, hydrants

**Table 2
continued**

Jurisdiction/Type of provision and public	Type of Hazard Definition	Buffer zone (vegetation)	Influence of terrain?	Prescriptions for structural elements (list)	Prescriptions for utilities
United States (Colorado, Florida, Oregon) Guidelines, dedicated to communities, planners and homeowners	Different methods for assessing risks and hazards in the WUI areas (highly detailed in the Florida document). Common use of a total hazard score based on partial scores for different features (i.e., vegetation, buildings, values, access, etc.)	Slightly different prescriptions between states. First area surrounding the building with heavily reduced fuel of 30 feet (about 9 m), as a common requirement	Factors addressed: slopes, terrain, generally considered in the risk assessment. Specific requirements only in Oregon guidelines	Some building construction guidelines, especially for roof covering and eaves, exterior walls, glazing, openings, decks	Some guidelines for supply level, water sources and their access in the Oregon guidelines
United States (California) Standards/Guidelines (for homeowners)	Three risk areas defined by the State and by local authorities (additional fourth risk area)	Up to 100 feet (30.5 m) for brush, flammable vegetation and other combustible growth (except for some specific cases)	Factors addressed: slopes. Different horizontal and vertical clearance between vegetation depending on slopes	Roof (including valley flashings, eaves and gutters), exterior walls and coverings (including roof eaves, ceilings and appendages), exterior glazing and doors, vents, attachments, underfloor areas. Ignition resistant materials defined	Not in the specific WUI part of the Fire Code

Table 2
continued

Jurisdiction/ Type of provision and public	Type of Hazard Definition	Buffer zone (vegetation)	Influence of terrain?	Prescriptions for structural elements (list)	Prescriptions for utilities
Australia Standards	Structures classified into seven classes of Bushfire Hazard Level (BAL), based on several factors, with detailed classification guidance	In the extreme bushfire risk area, at least 10 m between structures and vegetation. Otherwise, structures should comply with specific requirements. Specific guidance on fuel reduction and protection around structures in local regulations and guidelines	Factors addressed: slopes. Considered in the computation of Bushfire Hazard Levels. (also by local guidelines for defining the protection area width around structures)	Roof (including valley flashings, eaves and gutters), exterior walls and coverings, exterior glazing and doors, vents, attachments and detachments, floors and sub-floors. Some ignition resistant materials defined. Particular emphasis on external glazing and doors	Not specifically addressed in the reviewed standard. Guidelines about supply level, water sources, access and fire hydrants in local documents
New Zealand and Standards	Five levels of building types defined (Building Importance Levels, BIL), with respect to fire and the related risk for their occupants	Firebreaks should be cleared from vegetation (qualitative indications)	Not specifically addressed	Exterior walls, floors, other interior structures (walls and ceiling materials, fire cells). Specific provisions about maximum surface temperature of combustible materials and fire spread	Future planning progress for water supply. Provisions about escape routes

Table 2
continued

Jurisdiction/ Type of provision and public	Type of Hazard Definition	Buffer zone (vegetation)	Influence of terrain?	Prescriptions for structural elements (list)	Prescriptions for utilities
International Standards	Three classes of fire hazard and severity, depending on fuel models, critical fire weather frequency, slopes	Fuel modification (reducing/altering non-fire resistive vegetation) within: – 30 feet (9.14 m) for moderate hazards, – 50 feet (15.24 m) for high hazards, – 100 feet (30.48 m) for extreme hazards. Greater site-specific distances	Factors addressed: slopes, topographic factors (elevation, ridges, drainages, roads, exposure, etc.), interactions between man-made infrastructures and geography. Slopes considered in the definition of the severity classes and in the prescriptions for decks and detached structures	Roof (including valley flashings, eaves and gutters), exterior walls, exterior glazing and doors, openings, attachments and detachments, underfloor areas. Three ignition resistant classes, based on defensible space, fire hazard severity, water supply; ignition resistant materials	Water supply points, including prescribing prescriptions about supply level, water sources, access and supply and power
European Union Standards	Three risk zones should be individuated in the territory of the EU with respect to forest fires, based on risk assessment. WUI fires not explicitly mentioned	Not specifically addressed	Not specifically addressed	Not specifically addressed	Not specifically addressed
France (including local authorities) Standards	Two main risk areas (one where it is not possible to build new structures). Some regions defined as subject to forest fire risk	Vegetation clearing up to 50 m. A buffer distance of 200 m between new constructions and the forest. Specific local prescriptions (plans) for vegetation clearing	Factors addressed: slopes, orientation (e.g. with respect to wind), sunlight exposure. Influence of terrain in the definition of risk areas. Not considered for vegetation clearing	Roof (including eaves and gutters), exterior walls and coverings, vents, detached structures. All information in local guidelines	Water supply points. Specific local prescriptions (plans) for their characteristics and distance from structures

Table 2
continued

Jurisdiction/Type of provision and public	Type of Hazard Definition	Buffer zone (vegetation)	Influence of terrain?	Prescriptions for structural elements (list)	Prescriptions for utilities
Italy (including Regions) Standards/Guidelines (regional) dedicated to planners	Definition of interfaces and four danger zones (regional guidelines) based on several characteristics	Two areas of defensible space (within 10 m and 10–20 m of the structure), with different indications about fuel removal, reduction and substitution, clearance between vegetation and maintenance (regional guidelines). Different prescriptions for defensible space in the two regions considered	Factors addressed: slopes. Extension of the defensible space for high slopes (regional guidelines)	Building construction, change of land use destination, planting of new vegetation not allowed for defined periods in recently fire-prone areas.	Not specifically addressed
Canada (including Canadian provinces) Guidelines, dedicated to both communities and homeowners	Guidance on firefighters: cooperation, training and trust-building principles (agencies/practitioners)	<i>Wildfire Preparedness Guide</i> (for protecting values at risk, dedicated to emergency response personnel); <i>Wildfire Mitigation Strategy</i> (activities for reducing the impact of wildfires on values). Other plans: <i>Springer Deployment, Municipal Development, Municipal Emergency Management plans, Land Use Bylaws</i>	Buildings, in particular for combustible materials (debris, firewood, propane tanks, burning barrels, fire pits) and spark arresters	Fire history affects hazard definition and assessment	Definition of adequate access, road standards and fire service access routes

**Table 2
continued**

Jurisdiction/Type of provision and public	Prescriptions for firefighters	Type of plans required	Fire protection measures provided	Influence of environment/fire history?	Prescriptions for access
United States Standards	Specific provisions for planning, managing and assessing firefighting activities in case of wildfire disasters	<i>Fire protection plan, Mitigation plan</i> (including fuel modification provisions), and other plans concerning: <i>fire lanes, winter access maintenance, multi-agency operation</i> (not specific to wildfires), <i>minimum water supply, dry hydrant, fire response, preparedness, incident action, containment and control, construction</i>	Measures for water sources: connections for sprinkler systems, fire and dry hydrants. Measures for buildings: sprinklers, standpipe systems, fire extinguishers, spark arresters and provisions for storing combustible materials	Fire history considered in the ignition sources assessment	Provisions about the number of access routes, depending on households. Detailed standards for main roads, dead-end roads, fire lanes, parking, road signs and markers. Geometric and construction requirements. Vegetation clearing on roadsides
United States (Colorado, Florida, Oregon) Guidelines, dedicated to communities, planners and homeowners	Not specifically addressed	General guidelines on developing mitigation and response plans (Florida) and how to adhere to the <i>Firewise Communities Program</i>	Some generic measures for water sources (helicopter dip spots, Florida) and buildings (sprinklers, spark arresters, combustible materials)	Influence of some environmental factors on the hazard and risk assessment	Influence of some access factors on the hazard and risk assessment. Specific provisions for driveways and street markers (mainly Florida)
United States (California) Standards/Guidelines (for homeowners)	Not in the specific WUI part of the Fire Code	<i>Fire Protection Plan</i> for new constructions and modifications	Not in the specific WUI part of the Fire Code	Influence of environmental factors on defining hazard zones	Not in the specific WUI part of the Fire Code

Table 2
continued

Jurisdiction/ Type of provision and public	Prescriptions for firefighters	Type of plans required	Fire protection measures provided	Influence of environment/ fire history?	Prescriptions for access
Australia Standards	Not specifically addressed	Local guidelines requiring protection plans	Some fire protection measures in local guidelines (for water sources and private shelters)	Influence of some environ- mental factors on defining hazard zones	Provisions for main, access roads and fire trails in local guidelines (including e.g. 2 m of vegetation clearing on each side and 4 m high)
New Zealand Standards	Some qualitative indications	Provisions about <i>evacuation plans</i> (and related struc- tures)	Some indications about combustible materials and warning systems (mainly in the addi- tional guidelines)	Not specifically addressed	Some provisions/guidelines for markings, general provi- sions for access from roads to buildings
International Standards	Not specifically addressed	<i>Fire protection plan, Site plan</i> including specific informa- tion about wildfire expo- sure, <i>vegetation management plan</i> (not mandatory)	Measures for protecting water sources, sprin- klers, spark arresters and for storing com- bustible materials	Influence of environmental factors and fire history on defining wildfire risk, haz- ard zones, and fire protec- tion plans (fire history)	Specific prescriptions for standards of main roads and driveways, road signs and markers
European Union Standards	Not specifically addressed	<i>Fire protection plan</i> and a scheme for promoting, improving, and evaluating forest risk data	Not specifically address- ed	Fire history (previous 5 years) considered in defining fire protection plans for high-risk areas	Not specifically addressed
France (in- cluding local authorities) Standards	Storage of mate- rial for fire- fighting in designated pla- ces in the haz- ard zones	<i>Local Plan for preventing pre- dictable natural risk – forest fire</i> (including the definition of hazard zones and related prescriptions)	Not specifically address- ed	Influence of environmental factors and fire history on defining hazard zones	Clearing of roadsides in the hazard zones (up to 20 m both sides, 10 m for driveways). Specific prescriptions about geometric features in local plans

**Table 2
continued**

Jurisdiction/Type of provision and public	Prescriptions for firefighters	Type of plans required	Fire protection measures provided	Influence of environment/fire history?	Prescriptions for access
Italy (including Regions) Standards/Guidelines (regional) dedicated to planners	Definition of some possible firefighting activities in case of interface fires (regional plan)	Regional plan for forecasting, preventing and fighting wildfires, including a list of requirements, recommendations,, evacuation plans (regional)	Some qualitative measures about combustible materials and private shelters (regional plan)	Not specifically addressed	Some qualitative and more specific requirements for main road standards (regional plan and guidelines)

standards/guidelines reviewed, except for EU Standards. The same is valid for the prescriptions/guidelines about clearance between vegetation and structures and/or between different types of vegetation; and the prescriptions/guidelines about maintenance (pruning, removal of dead vegetation, etc.). Specific quantitative details concerning the defensible space are provided in Table 2. Local French provisions [37] on clearance are worthy of note due to the high level of details. For example, clearance between vegetation (trees and bushes) and other plants (e.g., vertical distance between the lower boundary of a crown tree and the top of a bush should be high ≥ 2 times the height of the bush, but anyway > 2 m); structures (e.g., trees should be at least 3 m from structures); power lines (e.g., high voltage lines ≥ 1000 V should be at least three meters from the vegetation) are mentioned.

4.2.2. Topography/Terrain Topographic and terrain factors are considered in all the groups of documents reviewed, except for EU and New Zealand standards/guidelines. Those factors can affect the definition of risk areas and/or the defensible space for standards/guidelines belonging to USA, California, Australia, France, Italy, and the IWUIC. In Canadian guidelines, the relative position between houses and slopes is considered. Specific quantitative details concerning the influence of topography/terrain are provided in Table 2.

4.3. Building Construction

Provisions/recommendations about the building materials and structures to be adopted in wildfire-prone areas are provided in all the standards/guidelines reviewed, except for the EU Standards. The level of detail of the provisions/guidelines is extremely variable across the different locations/jurisdictions considered, as reported in Table 2.

4.3.1. General Requirements General requirements about construction materials to be used in hazard zones and ignition resistance of building materials have been found in all standards/guidelines except for the EU, French and Canadian guidelines. Some generic requirements have been found in the Californian and Italian standards. A detailed definition of ignition resistance classes can be found in the standards reviewed from Australia (Fire Resistance Level -FRL- determined through three ratings obtained from a standard test representing: structural adequacy, integrity and insulation) and International standards (three classes of ignition resistance -IR- obtained as a combination of three fire hazard severity classes, and of classes of conformity of water supply and defensible space to standards). A detailed requirements of ignition resistance for materials can be found in standards/guidelines reviewed from USA, Australia and the IWUIC code, with reference to results of standard tests. The prescribed minimum separation distance between buildings varies between 4.5 m and 15.2 m (US standard, depending on building height, type, presence of sprinklers), 9 m (Canadian guidelines, for high-density dwellings), and 10 m [5].

4.3.2. Roof Requirements concerning roofs have been found in all standards/guidelines reviewed except for New Zealand, EU and Italy. Provisions about roof covering, eaves and gutters are given in all those standards/guidelines (except for gutters in Canadian guidelines). Provisions about valley flashing (i.e., material to be used, non-combustibility, thickness, etc.) are given only in the Australian, Californian and International standards/guidelines. Generally, provisions concerning roof covering and eaves consist in defining materials to be used and their ignition resistance.

4.3.3. Walls and Other External Coverings Requirements concerning walls and other external coverings have been found in all standards/guidelines reviewed except for EU and Italy. Provisions about exterior walls have been given in all those standards/guidelines. Provisions about wall coverings have only been found in the French and Californian standards/guidelines reviewed. Generally, provisions concerning exterior walls consist in defining materials to be used and their ignition resistance.

4.3.4. Windows, External Doors and Vents Requirements concerning windows, external doors and vents have been found in all standards/guidelines reviewed except for New Zealand, EU and Italy. Provisions about exterior glazing, external doors and vents have been given in all those standards/guidelines (except for exterior glazing and doors in French documents reviewed, and Canada for doors). Generally, provisions concerning glazing and doors consist of defining materials to be used and their ignition resistance. Prescriptions/guidelines concerning vents and other openings are related to their corrosion-resistance and to the presence of openings in the metal grid.

4.3.5. Decks and Detachments Requirements concerning decks and detachments have been found in all standards/guidelines reviewed except for New Zealand, EU and Italy. Provisions about decks and other attachments have been found in all those standards/guidelines (except for France). Provisions about detached structures have been given in the documents reviewed for USA, Australia, International, France. Generally, provisions concerning decks and other attachments consist in defining materials to be used and their ignition resistance. Provisions/guidelines concerning detachments include also other information such as the distance from the main structures (i.e., minimum 9 m in US standards, 6 m in Australian standards, except if accessory structures comply with requirements for main structures or they are separated through appropriate walls, 50 feet/15.24 m in the IWUIC, otherwise accessory structures should mostly comply with same requirements for exterior walls).

4.3.6. Floor and Interior Structures Requirements concerning floors and interior structures have been found in all standards/guidelines reviewed except for EU, France and Italy. Provisions regarding under-floors have been found in all those documents, except for New Zealand. Provisions about floors have been found only in Australian and New Zealand standards, while provisions about other inte-

rior structures only in New Zealand standards (where fire-cells are defined: inside spaces, enclosed by a combination of fire separations, external walls, roofs and floors). Generally, provisions concerning floors consist in defining materials to be used and their ignition resistance.

4.4. Resources

Provisions/recommendations about resources in wildfire-prone areas have been provided in all the standards/guidelines reviewed, except for the EU, Californian and Italian standards. The level of detail of the provisions/guidelines varies between the different jurisdictions/areas considered, as reported in the summarizing Table 2. For the United States, Australia and in the IWUIC, the provisions are more quantitative and detailed.

4.4.1. Utilities The category “utilities” includes requirements mainly concerning water supply, but also other means such as evacuation routes (for New Zealand). Requirements concerning water supply have been found in all standards/guidelines reviewed except for California, EU and Italian Standards/Guidelines. Generally, provisions/guidelines concerning supply level, water sources, access for water sources and hydrants are given for water supply. A very detailed definition of water supply was found in the US standards, as a function of the total volume of the structure, the occupancy hazard and construction classification, and the hazard exposure. The minimum level of water delivery rate to the fire scene is determined as well (to be provided at the same level for at least 1–2 h at 138 kPa), based on the water supply level. According to US standards, water sources should be maintained, accessible and they should guarantee the same capacity and delivery on a 1-year basis. Specific standards for fire hydrants are provided concerning markings, location, spacing, pipe diameters, dead-end pipes. Standards are provided for dry hydrants for non-pressurized water supply as well. Other detailed definitions have been found in the IWUIC and the Australian guidelines. In the IWUIC, the minimum water supply for new buildings, not equipped with sprinkler systems in the WUI area, is set to 63–95 l/s for 30 min–2 h, depending on floor area and the number of families. The water source should be ≤ 305 m far from the building and the natural water sources should guarantee a minimum water supply, being equipped with hydrant/draft site.

4.4.2. Firefighters Requirements concerning firefighters have been found in standards/guidelines from Canada, USA, New Zealand, France and Italy (in the Italian case, some information was found in regional guidelines). In this case, the provisions/guidelines found are heterogenous and scarce. For example, in Canadian guidelines, the cooperation between partner agencies of fire protection, training and exercises are encouraged. In the US standards, the required number of firefighters are assessed, and the safety requirements and procedures to be followed in case of incident are described.

4.4.3. Planning Requirements concerning planning have been found in all standards/guidelines reviewed. In particular, provisions about fire protection plans have been found in all the other documents reviewed, except for New Zealand. Some requirements concerning other types of plans different than fire protection plans, which may be of interest for WUI fire safety (such as emergency or development plans), are mentioned in all the other documents, except for California and France. More detailed provisions about required plans have been found in the US standards/guidelines and the Canadian guidelines reviewed. Further details concerning plans provided in all the documents reviewed are reported in Table 2. The Canadian guidelines include plans for high wildfire hazard and risk zones: the Wildfire Preparedness Guide, the Wildfire Mitigation Strategy. Other plans suggested are the sprinkler development and the municipal development plans, the municipal emergency management program guide and the land use bylaws. The US standards require a mitigation plan including prevention activities, fuel modifications, hazard mitigation for structures, public information, infrastructures. Other plans required by the US Standards are: a fire lane, wintertime access maintenance, multi-agency operational, minimum water supply, dry hydrant, fire response, preparedness, incident action, containment and control, construction plans.

4.4.4. Outreach The outreach in standards/guidelines is variable, depending on the type of document reviewed. Generally, guidelines for creating defensible space, clear and maintain vegetation or similar activities are included in documents intended for use by the general public (e.g., Canadian or Californian guidelines). Some regulations can be implemented at a local level with modifications allowed (such as the IWUIC Code which can be adopted by other jurisdictions).

4.5. Fire Protection Measures

Provisions/recommendations about fire protection measures to be adopted in wild-fire-prone areas are provided in all the standards/guidelines reviewed, concerning measures for water sources and buildings, except for the EU and French Standards. The level of detail of the provisions/guidelines varies between the different areas considered. In fact, the level of detail of Canadian, Californian and Italian standards is limited. The most significant measures are reported in the sections below and summarized in Table 2.

4.5.1. Measures for Water Sources Requirements concerning measures for water sources have been found only in US, Australian and International standards/guidelines reviewed. Generally, provisions consisted of defining clearing, defensible space, materials, protection and connections for water sources. The American provisions/guidelines reviewed are the most detailed. The provisions require that: the fire department connections for sprinkler systems should be < 100 feet (30.5 m) far from fire hydrant; the space around fire hydrants protected by barriers should be cleared. Protections are required for dry hydrants as well.

4.5.2. Measures for Buildings Requirements concerning measures for buildings have been found in all standards/guidelines reviewed except for EU and France. Only some provisions/guidelines have been found in Californian standard (for combustible materials), in Australian standard (for private shelters), and in Italian local standards (for combustible materials and private shelters). Generally, provisions/guidelines concerning sprinklers, protection and warning systems consist in setting the conditions where they are needed and the tools needed. For example, the US Standards require that all residential buildings and all the buildings with > 2 stories or > 30 feet (9.1 m) tall (with some exceptions) should be provided with automated sprinkler systems. Standpipe systems with specific fire department connections (at indicated distances) and fire extinguishers should be installed in new buildings and other specific buildings in case of available municipal water systems. Automatic fire warning systems, with different prescriptions for residential and non-residential structures should be installed as well. Combustible materials, unprotected heat and flame sources, inappropriate storage of liquefied petroleum gas should be avoided within 30 feet (about 9 m) of the structure.

4.6. Environment

Provisions/indications about the environmental factors related to wildfire-prone areas are provided only in some of the standards/guidelines reviewed: American Standards and Guidelines (only for weather in California), Australian standard (only for weather), IWUIC Code, French provisions and guidelines, EU Regulations (only for fire history), as summarized in Table 2. Environmental factors are consistently used for risk assessments and definition of hazard zones.

4.6.1. Weather Weather is mentioned in all standards/guidelines reviewed in the procedures for wildfire risk and hazard definition or for developing fire protection plans (France), except for Canada, New Zealand, EU and Italy. The weather factors generally considered are: wind, humidity, temperature, precipitation and fuel-related features (e.g., fine fuel moisture).

4.6.2. Fire History Requirements concerning fire history have been found in all standards/guidelines reviewed except for California, Australia, New Zealand and Italy. Fire history factors in the standards/guidelines reviewed have been considered mainly for defining risk areas or severity zones; or for developing fire protection plans (International standard).

4.7. Access

Provisions/recommendations regarding accessibility and road standards to be adopted in wildfire-prone areas are provided in all the standards/guidelines reviewed, except for the EU Regulations and in the section of the California Fire Code concerning WUI fires. The level of detail of the provisions/guidelines varies between the different areas considered, as summarized in Table 2. Provisions concerning type/number of access roads, road standards, markings (only in US, New Zealand and International standards) and vegetation clearing between roads and

vegetation (only in US, Australia and French standard/guidelines). The US standards reviewed are the most detailed with respect to access requirements. Generally, the types of access roads/routes are defined in the appropriate section of standards/guidelines. Access routes for emergency vehicles, fire service, and public are considered. In the US standard, the number of access routes required is set, depending on the number of households or parking spaces (e.g., 3 for > 600 households or > 3000 parking spaces in case of mixed areas). Provisions/guidelines concerning road standards include geometric standards, pavements, turn-arounds, clearance, loads. In particular, in the US Standards requirements concerning materials, minimum clear width, minimum vertical clearance, minimum curve radius, intersection control, traffic calming measures, hydraulic calculations for bridges and culverts, grades, emergency pull-offs, maximum angles of approach and departure are considered. Generally, provisions/guidelines about markings concern visibility, location and text on markings.

Standards/guidelines are normally not provided with requirements for vegetation clearing around roads. An example of these requirements is reported in the French standard reviewed: both sides of public roads in hazard zones should be cleared within 20 m, and driveways of structures < 200 m from the forest, should be cleared from vegetation for a distance of 10 m.

5. Discussion

In this section, we identify the common approaches found and the deficiencies in the reviewed standards/guidelines. A graphical representation of the variables which can be consistently/partially found or which are neglected in the standards/guidelines reviewed (see Table 1) is presented in Fig. 3. This figure is simplified given the need to represent several levels of information in a single summary. Generally, provisions/guidelines vary between different jurisdictions in the quantitative assessments of the various variables considered, and in the methods used for defining measures and indicators. However, some common approaches have been found.

At a general level, the standards reviewed seem to put a great emphasis on the assessment of both risk and hazard as well as the use of risk mitigation measures concerning vegetation. It should be noted that fire risk mitigation measures (e.g. actions on vegetation) are considered in this context within the requirements on buffer zone and type of plans required. In contrast fire protection measures are intended as those measures limiting the impact or reducing the fire (e.g. sprinklers, etc.). The definitions of wildfire risk and hazard levels in the standards/guidelines reviewed are mainly based on topographic, vegetation and environmental factors (except for New Zealand, in which buildings are classified based on risk to their occupants in the event of fires). Methods for identifying and classifying severity in WUI areas are present in the standards/guidelines reviewed, with different level of refinement. This may include a sum of partial ratings based on different factors (e.g., vegetation types, slopes, distance between structures and vegetation) or they can be based on fire history, such as the case of the EU Guidelines. In this con-

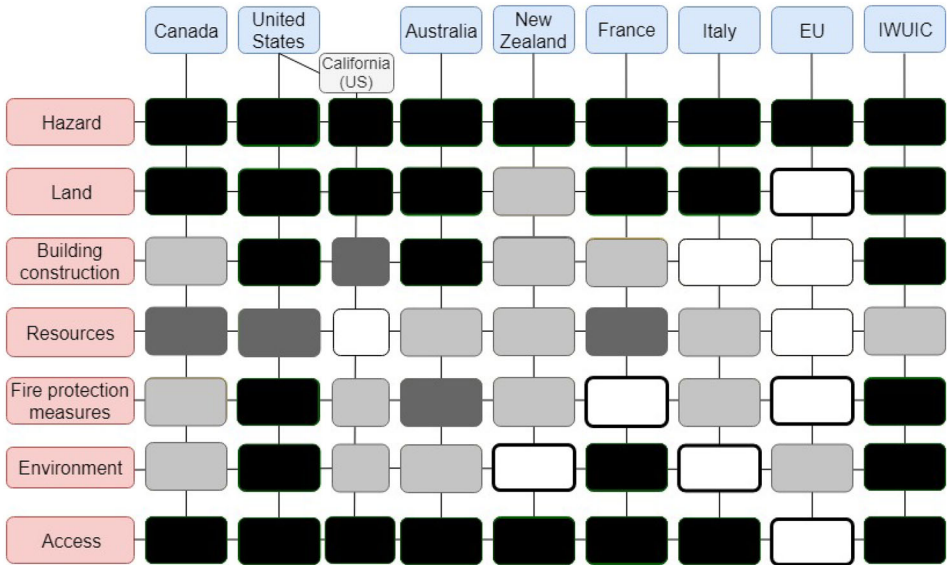


Figure 3. Simplified graphical representation of the variables and provisions/recommendations considered in the standards/guidelines reviewed from different countries. Legend: black if all second-level sub-categories are considered in detail for the relevant macro-category listed on the left of the figure, dark grey if all second-level sub-categories are considered but some of them are less detailed, light grey if at least one second-level sub-category is missing, white if only one second-level sub-category is adequately considered, white with bold contour if the first-level macro-category is neglected.

text, weather is often considered for defining risk areas or severity zones. The consideration of fire history for defining risk areas or severity zones was retrieved in some groups of standards/guidelines as well. The concept of defensible space is present in the standards/guidelines reviewed except in the EU regulations. The same is valid for prescriptions/guidelines for vegetation clearance and distance between vegetation and other vegetation/structures; and for the influence of topographic and terrain factors (except for EU and New Zealand). Those factors generally affect the definition of risk areas (and/or defensible space), or the position between houses and slopes (Canada). Overall, it seems evident that risk/hazard assessment and mitigation measures appear as key requirements to be included in a WUI fire code and they were addressed (although with slightly different approaches) in all standards reviewed.

Requirements concerning building construction seem to be less consistent among standards and provisions. General requirements for construction materials and ignition resistance have been found in most of the standards/guidelines reviewed (except for EU, France, Canada), although in some instances they are only broadly outlined (e.g., in the Californian and Italian standards) rather than

treated in detail. Both the type of construction materials and elements taken into consideration as well as the provisions/requirements provided greatly vary among standards. This seems to indicate a lower level of maturity in the understanding of the solutions needed to address this issue and highlight the need for further research in addressing standardized methods to provide guidance. It should also be noted that construction materials and processes may vary across countries (e.g., some countries may have long-standing tradition towards a specific type of material rather than another), thus any international guidelines should be reviewed and made applicable to the local building materials. For example, explicit references to fire-retardant treated woods for constructions mentioned in the IWUIC code were also found only in US and Canadian standards/guidelines.

At a general level, the requirements concerning resources also greatly vary among standards. Great emphasis is placed on requirements concerning water supply (supply level, water sources, access, hydrants) as those have been found in all standards/guidelines reviewed (except for California, EU, Italy). This is also linked to the actual definitions of water supply provided. Emphasis is placed also on fire protection plans, although with varying level of details. Commonly discussed variables in fire protection plans are weather and fire history. Similarly, the provisions concerning outreach are variable, depending on the type of document reviewed. Generally, guidelines for creating defensible space, clear and maintain vegetation are dedicated to the general public (homeowners, communities and/or planners). Some regulations can be implemented at a local level with modifications allowed. Most standards also include requirements concerning measures for buildings (sprinklers, protection and warning systems), although those are presented with varying levels of refinement.

Requirements concerning access have been found in most of the standards/guidelines reviewed (except for California, retrievable in the general Fire Code, and EU). Those generally discuss the type/number of access roads, and road standards (geometry, pavements, turnarounds, clearance, loads).

A set of deficiencies can be highlighted in groups of standards/guidelines. In fact, the requirements concerning resources (firefighters and other types of utilities), fire protection measures (especially for water sources) are often missing or limited in many of the standards/guidelines reviewed. In particular, requirements concerning resources (firefighters) have been found only in standards/guidelines from Canada, USA, New Zealand, France and Italy. Note that other types of utilities, such as evacuation routes, have only been found in New Zealand standards. Requirements concerning measures for water sources (clearing, defensible space, materials, protection, connections for water sources) have only been found in the USA, Australian and International standards/guidelines reviewed.

For other variables, the level of detail of some groups of standards/guidelines is limited to high-level provisions (i.e., only for some sub-categories considered in Fig. 1). This is particularly the case for requirements for building construction and road access. While all the standards/guidelines reviewed make provisions for specific building elements, some categories of parameters reviewed are neglected in some cases. For example, standards from Italy and EU do not consider walls, windows and other openings, decks/detachments, floors/under-floors. Those from

New Zealand do not consider windows and other openings and decks/detachments. Moreover, among the third-level sub-variables listed in the methods section of this paper, wall coverings are considered only in the French and Californian standards/guidelines reviewed. Provisions about floors (by defining materials to be used and their ignition resistance) have been found only in Australian and New Zealand standards (including provisions about other interior structures). Moreover, while most of standards/guidelines include general requirements for roads (i.e., road standards), some detailed variables have not been considered, such as road markings. The latter provisions (considering visibility, location, text of markings) have only been found in the USA, International and New Zealand standards.

Another limitation was found in relation to how environmental factors (weather and fire history) are taken into account for defining risk areas or plans. In particular, weather is only considered in the USA, Australian, French and International standards/guidelines reviewed. In contrast, fire history is only considered in the USA, Canadian, French, EU and International standards/guidelines reviewed. This seems to indicate that there is still not an international consensus on the variables to be considered during the definition of risk areas. Further research should explore if these differences in the approaches are mostly driven by the choice of the regulators or are the result of the local/regional conditions.

6. Conclusions

This paper presents a review a selection of international standards and guidelines concerning fires in the Wildland-Urban Interface areas. A template was developed and used to consistently present the information regarding hazard, land, building construction, utilities, fire protection measures, environment and access. The main objective was to document the provisions and enable a comparison between the regulations/guidance examined, in order to identify the underlying common threads and the main deficiencies. This comparison is summarized in Table 2 and then discussed.

In some locations, provisions for WUI fires are included in general Fire Codes (e.g., California); elsewhere, requirements are implemented at a local level (e.g., France and Italy). Some countries have standards specifically dedicated to the issue of WUI fires (e.g., USA and Australia).

Based on the review conducted, the following main common themes can be highlighted: the definition of WUI risk areas and severity classes for these areas, the influence of land factors including the definition of defensible space, recommendations/requirements for building construction components/materials and road access. Whereas, the following main deficiencies can be highlighted among others: the requirements/recommendations about resources, fire protection measures (for water sources), and the consideration of environmental factors are scarce or absent in several documents reviewed. Moreover, differences in the methods for defining severity classes and in the requirements for buildings have been particularly highlighted.

The recommendations and requirements identified from the standards and guidelines considered may be useful for the development or revision of future standards/guidelines concerning WUI fires prevention, protection, planning and management. This might become increasingly important as the problem evolves, especially in those jurisdictions where WUI was previously not a concern, and therefore, there is no history of adopting regulatory guidance in this domain. Moreover, the identification of common deficiencies in the existing standards and guidelines reviewed may help in setting goals for future research and/or to transfer existing research into practice. In this sense, results from the presented review may be of use for both researchers and practitioners.

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References

1. Alberta Government (2013) FireSmart Guidebook for community protection. A guidebook for wildland-urban interface communities
2. Anderson SA, Doherty JJ, Pearce HG (2008) Wildfires in New Zealand from 1991 to 2007. *N Z J For* 53(3):19–22
3. Australian Standard (2009) Construction of Buildings in Bushfire-Prone Areas. AS 3959-2009
4. Bianchi R, Lucas C, Leonard J, Finkle K (2010) Meteorological conditions and wild-fire-related house loss in Australia. *Int J Wildland Fire* 19(7):914–926
5. Bovio G, Camia A, Marzano R, Pignocchino D (2001) Prevenzione antincendi boschivi in zona di interfaccia urbano foresta. Università di Torino–Regione Piemonte
6. California (2016) California code of regulations. Title
7. California Building Standards Commission (2016) California building code
8. Caton SE, Hakes RSP, Gorham DJ, Zhou A, Gollner MJ (2016) Review of pathways for building fire spread in the wildland urban interface part i: exposure conditions. *Fire Technol*. <https://doi.org/10.1007/s10694-016-0589-z>
9. Dennison PE, Cova TJ, Mortiz MA (2007) WUIVAC: a wildland-urban interface evacuation trigger model applied in strategic wildfire scenarios. *Nat Hazards* 41(1):181–199

10. Département de la Haute-Corse (2013) Arrêté n. 2013071-2002 (2013.03.12) Relative au Débroussaillage légal
11. Department of Building and Housing (2012) New Zealand building code (extract): clauses C1–C6 protection from fire, clause A3: building importance levels
12. Edell S (Colorado State Forest Service) (2002) Colorado wildland urban interface hazard assessment methodology
13. European Commission (1992) Council Regulation (EEC) No 2158/92 of 23 July 1992 on protection of the Community's forests against fire
14. European Council (2003) EC 2152/2003 concerning the "Monitoring of forests and environmental interactions un the Community (Forest Focus)
15. Fire and Emergency New Zealand (2017) Fire and Emergency New Zealand Act
16. Firewise USA Program (National Fire Protection Association) (2016) Firewise Toolkit
17. Florida Department of Agriculture and Consumer Services (2002) Wildfire Hazard assessment guide for Florida Homeowners
18. Republique Francaise (2017) Code forestier
19. Ganteaume A (2016) Le risqué incendie dans les itnerfaces habitat-forêt. Guide technique
20. Glickman D, Babbitt B (2001) Urban wildland interface communities within the vicinity of federal lands that are at high risk from wildfire. *Fed Reg* 66(3):751–777
21. Government of South Australia (2017) South australia development regulations 2008 (retrieved 2017)
22. Government of Tasmania (2005) Guidelines for development in bushfire prone areas of Tasmania, bushfire planning group
23. International Association of Wildland Fire (2012) WUI fact sheet
24. International Code Council (ICC) (2015) International Wildland Urban Interface Code (IWUIC)
25. Intini P, Ronchi E, Gwynne S, Pel A (2019) Traffic modeling for wildland-urban interface fire evacuation. *J Transp Eng A Syst* 145(3):04019002
26. Johnston LM (2016) Mapping Canadian Wildland fire interface areas
27. Jolly WM, Cochrane MA, Freeborn PH, Holden ZA, Brown TJ, Williamson GJ, Bowman DM (2015) Climate-induced variations in global wildfire danger from 1979 to 2013. *Nat Commun* 6
28. Legambiente (2017) Dossier Incendi 2017 (Fire Report 2017)
29. Manzello SL, Bianchi R, Gollner MJ, Gorham D, McAllister S, Pastor E, Rein G, Suzuki S (2018) Summary of workshop large outdoor fires and the built environment. *Fire Safe J* 100:76–92. <https://doi.org/10.1016/j.firesaf.2018.07.002>
30. Mell WE, Manzello SL, Maranghides A, Butry D, Rehm RG (2010) The wildland–urban interface fire problem—current approaches and research needs. *Int J Wildland Fire* 19(2):238. <https://doi.org/10.1071/WF07131>
31. Modugno S, Balzter H, Cole B, Borrelli P (2016) Mapping regional patterns of large forest fires in Wildland–Urban Interface areas in Europe. *J Environ Manag* 172:112–126
32. National Fire Protection Association (2013) Standard for reducing structure ignition Hazards from Wildland Fire. NFPA 1144
33. National Fire Protection Association (2017) Standard on water supplies for suburban and rural fire fighting. NFPA 1142
34. Obama B (2016) Implementation guidelines for executive order 13728 WUI Federal Risk Management
35. Oregon Department of Land Conservation and Development (2000) Planning for natural hazards: wildfire technical resource guide

36. Paveglio TB, Moseley C, Carroll MS, Williams DR, Davis EJ, Fischer AP (2015) Categorizing the social context of the wildland urban interface: adaptive capacity for wild-fire and community “archetypes”. *For Sci* 61(2):298–310
37. Prefet de la Haute-corse (2011) Plan de Prevention des Risques Naturels previsibles. ‘Incendies de Foret’. Commune de Borgo (Corse). Reglement
38. Presidenza del Consiglio dei Ministri, Italia (2017) Attività Antincendio Boschivo per la stagione estiva 2017. Raccomandazioni per un più efficace contrasto agli incendi boschivi, di interfaccia e ai rischi conseguenti. Allegato
39. Radeloff VC, Helmers DP, Kramer HA, Mockrin MH, Alexandre PM, Bar-Massada A et al (2018) Rapid growth of the US wildland-urban interface raises wildfire risk. *Proc Natl Acad Sci* 115(13):3314–3319. <https://doi.org/10.1073/pnas.1718850115>
40. Regione Molise. Assessorato Agricoltura, Foreste e Pesca Produttiva (2004) Piano Regionale per la Previsione, Prevenzione e Lotta attiva contro gli Incendi Boschivi (L. 20/11/2000 n.353, 2004/06)
41. Repubblica Italiana (2000) Legge quadro in materia di incendi boschivi (Framework law concerning wildfires). L. 21.11.2000 n.353
42. Ronchi E, Gwynne SMV, Rein G, Intini P, Wadhvani R (2019) An open multi-physics framework for modelling wildland-urban interface fire evacuations. *Saf Sci* 118:868–880. <https://doi.org/10.1016/j.ssci.2019.06.009>
43. Ronchi E, Rein G, Gwynne S, Wadhvani R, Intini P, Bergstedt A (2017) e-sanctuary: open multi-physics framework for modelling wildfire urban evacuation. Fire Protection Research Foundation, Quincy
44. Shindler B, Olsen C, McCaffrey S, McFarlane B, Christianson A, McGee T, Curtis A, Sharp E (2014) TRUST. A planning guide for wildfire agencies and practitioners
45. State Board of Forestry and Fire Protection, California Department of Forestry and Fire Protection (2006) General guidelines for creating defensible space
46. State of California (2016) California Fire Code (Chapter 49: requirements for wildland-urban interface fire areas)
47. Stewart SI, Radeloff VC, Hammer RB (2003) Characteristics and location of the wildland-urban interface in the United States. 2nd International Wildland Wildfire Ecology and Wildfire Management Congress. Orlando, Florida. Retrieved from http://cnrf.iles.uwsp.edu/CLUE/Forest%20megatrends/page%207_human/old%20files/p7_WUI_text.doc