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Towards an integrated model for designing for building survival in bushfires

G. C. RAMSAY[1], N. A. McARTHUR[1] AND L. RUDOLPH[2]

[1] CSIRO Division of Building, Construction and Engineering, PO Box 56, Highett 3190, Victoria.

[2] The University of Melbourne, Parkville 3052, Victoria.

ABSTRACT

To date, there have generally been two approaches to mitigating building destruction. One approach has been to manage the vegetation (the 'landscape approach') whereas the other has been to select building materials and designs to minimize the effect of the bushfire attack (the 'building approach'). There is a need to combine these two approaches and this paper suggests that it can be done on the basis of the agents by which bushfires ignite, damage and destroy buildings, *viz.* burning debris, radiant heat, flame and wind.

A model to combine these approaches might be comprised of three modules:

(a) the first module is the potential bushfire attack, based upon the properties of the vegetation producing that attack;

(b) the second module is the modification of the attack by the environmental conditions and the landscape (this provides the opportunity to use the 'landscape approach'); and

(c) the third module is the reaction of building materials and design to the (modified) bushfire attack (this provides for the 'building approach').

This paper describes such an integrated model, briefly discusses the current state of knowledge with regard to the modules and the research that is needed to realize a quantitative model.

INTRODUCTION

A significant portion of the cost of bushfires in Australia is the destruction of buildings and the loss of life. For example, the 1983 Ash Wednesday fires in Victoria and South Australia caused the loss of 76 lives and damage estimated at $400 million which included some 2463 houses (Ramsay *et al.* 1986). Most of the buildings at risk were those situated at the interface between urban development and the countryside. Such development is increasing as cities and towns spread, lower-priced housing is needed, and the demand for recreational and permanent housing increases in areas where landscape and indigenous vegetation provide desirable environments. The nature of the countryside comprising the interface varies considerably and may include farms, orchards, forest plantations, national parks, state forests and undeveloped areas. However, the most desirable areas appear to be those with an abundance of indigenous vegetation, and consequent high bushfire potential.

These trends reinforce the need to give more attention to design for the survival of buildings in bushfires and for better information to facilitate such activities. This paper addresses the need for an integrated model, based on the underlying mechanisms which cause the ignition and destruction of buildings, which could be used to facilitate the design of buildings and their surrounding landscape.

MECHANISMS OF BUSHFIRE ATTACK

The mechanisms of bushfire attack, which have been established (Barrow 1945; Cole 1983; Ramsay *et al.* 1986; Wilson and Ferguson 1986) by examination of buildings (or their remains) which have been subjected to bushfires, are:

(a) ignition by burning debris (carried by wind);

(b) ignition and damage by radiant heat;

(c) ignition by flame contact; and

(d) damage caused by wind accompanying the fire.

Ignition by burning debris is generally believed to be the major mechanism and this may occur in a number of ways. The burning debris, along with other windborne combustible material such as leaves and twigs, can:

(a) pile up against combustible materials used at, or near, ground level as stumps, posts, subfloor enclosures, steps, door frames and window frames;

(b) accumulate on combustible materials used for decks, verandahs, pergolas and window sills;

(c) lodge in gaps and crannies in combustible materials used for exterior wall cladding, window frames and door frames; and

(d) gain entry to the interior of the building through broken windows (damaged by radiant heat, the force of the wind or flying debris), or through gaps in the exterior wall or roof cladding. Once inside the building, the burning debris may ignite framing, fittings and contents.

The small ignitions induced gradually get larger, involving other combustible parts of the building and its contents, until the building becomes totally involved in fire.

Heat radiated from a bushfire may assist ignition caused by burning debris. It may do this by preheating the building and its contents, or by breaking the glazing of windows, allowing burning debris to enter the building. In extreme cases, the heat may be sufficient to directly ignite the combustible exterior parts of the building and the interior furnishings situated near windows. Flame from the bushfire may also ignite combustible exterior parts of the building, particularly if vegetation located directly against the building catches alight.

Wind carries burning debris, driving it against or into a building, as well as large items such as branches and building materials which may break windows and damage roofing. The forces produced by the wind may also damage a building by breaking windows, removing portions of the wall and roof cladding or loosening them; this assists the entry of burning debris and leads to the ultimate destruction of the building.

CURRENT DESIGN APPROACHES

To date, there have generally been two approaches to mitigating building destruction. The first approach has been to manage the vegetation by means of fuel reduction and firebreaks. This approach has become more sophisticated with the use of measures such as windbreaks, suitable location of amenities and protective plantings, and is referred to in this paper as the 'landscape approach'. The second approach has been to select building materials and designs which were believed to minimize the risk of the bushfire damage. This 'building approach' tends to assume a certain level of bushfire hazard and 'designs against it'.

Present design processes tend to reinforce this dichotomy, with the building design and construction being separate and preceding any detailed consideration of the surroundings of the building and landscape design. When professional designers are employed, different people generally carry out the design of the building and the landscape, even if they are from the same practice, further enhancing the division of the design process. Ideally, for all the reasons discussed below, the two design processes should be carried out concurrently, enabling interaction between the two approaches. However, where this is not practical, it is preferable for at least the overall landscape design to be carried out *before* the building design. This would provide the opportunity to include desirable landscape measures, which may otherwise be precluded by the siting or design of the building.

THE NEED FOR A COMBINED APPROACH

Proponents of the landscape approach to designing (especially when confined to fuel reduction) have suggested that eliminating or reducing the bushfire attack at its source is the most effective and practical course of action, especially given the reluctance of builders and owners to incorporate recommended bushfire measures into new and existing buildings. However, to ensure building survival solely by this means would often necessitate a degree of fuel removal, which is unacceptable to many people, and remove much of the attractiveness of 'living in the bush'. Where allotments are small, such fuel reduction may require the cooperation of the owners of neighbouring allotments. In some cases the 'neighbouring allotments' may be extensive public lands such as forests and conservation areas where substantial landscape measures are neither possible nor desirable. Furthermore, burning debris may travel considerable distances and removing the vegetation in the vicinity of the building would not eliminate this hazard. Taken to its extreme, this is an argument for either the removal of most indigenous vegetation or its replacement by exotic vegetation. In addition, there is the problem of the long-term maintenance of such fuel reduction measures.

Proponents of the building approach take the view that useful modification of the landscape (especially vegetation) is not feasible either in the practical sense or politically, that the building itself should be built in such a way as to prevent its ignition and destruction and that people should be encouraged to stay in their buildings during a bushfire to ensure this. This approach becomes more and more difficult to accomplish as the fire hazard of the landscape increases and the cost of further building measures increases accordingly. The 'concrete bunker' is the ultimate outcome of this approach. In addition, there is no guarantee that people will be:

(a) with the building at the crucial time;

(b) be able to extinguish multiple ignitions before they grow to the stage that they are out of control; or

(c) aware of all the ignitions which have occurred.

Without a combined approach, landscape and building measures tend to be implemented independently, leading to either a reliance on one approach to the exclusion of the other or the use of both approaches regardless of the benefits of the other (a 'belt and braces' approach). In both cases, other requirements for the development such as retention of the vegetation amenity, passive solar design and large areas of glass for views may be sacrificed in the pursuit of building survival. This points to one of the strengths of a combined approach: the flexibility to accommodate other requirements by judicious choice of both landscape and building measures. This flexibility leads to a range of design solutions most appropriate to the development, and to possible consequent cost savings. For example, there may be a situation where there is a desire to have large windows facing a particular direction for aesthetic reasons and sunshine penetration into the building. The windows that satisfy these objectives could be a serious weakness in a bushfire because they could be cracked by radiant heat or broken by windborne objects, thus allowing burning debris to enter. Even if unbroken, they could admit radiant heat into the interior making combustibles more prone to ignition by embers.

There are many possible options to solve this conflict and protect the building:

(a) use special glass which is resistant to breaking;

(b) reduce the size of the panes of glass;

(c) use metal insect screens externally to catch embers and reduce radiant heat;

(d) use metal shutters (sliding, vertical, rolling or hinged);

(e) avoid locating any external combustible structures close to these windows;

(f) protect these windows externally with suitable planting located to form a barrier or deflector for wind, windborne debris and radiation;

(g) manage the vegetation for a given distance outside these windows to reduce ember, radiation and flame attack.

It will be seen that the first five options listed are *building* options and the last two are *landscape* options. Some of these options can be used in combination thus adding to the flexibility of a combined approach.

The combination of the landscape and building approaches model is most practically achieved by a consideration of the individual measures that might be applied for each building element. In the present state of knowledge, the matching of a finished landscape design with a complete building design is not yet possible as there is no quantitative measure of either with regard to bushfire hazard or bushfire performance respectively.

AN INTEGRATED MODEL

For the effective combination of the landscape and building approaches, it is desirable to have a model of the urban interface under bushfire conditions. Such a model, coupled with a bushfire spread model, could be used not only for the design of building and its surrounding landscape, but also for fire prevention and firefighting activities to minimize much of the building loss.

A Structure Ignition Assessment Model (SIAM) has been proposed (Cohen *et al.* 1991) which comprises three major modules for 'fire behaviour', 'heat transfer' and 'building ignition' with a subsidiary 'fire brand' module. This model appears to concentrate on ignition of combustible elements of the building exterior and does not include ready provision for the integration of landscape measures and design. In addition, 'heat transfer' by way of radiation and flame contact is a major module of the model rather than the 'fire brand' module, despite the assumption (Tran *et al.* 1992) that 'ignition by burning debris plays a very important role in the ignition of structures'.

We believe that a more appropriate model, based on the elements of bushfire attack (burning debris, radiation, flame and wind) might have three modules which:

(a) quantify the potential attack according to the vegetation types and quantities;

(b) modify the attack according to the environmental conditions and landscape features; and

(c) determine the response of the building according to its materials and design.

Bushfire Attack Module

Although there is an extensive body of literature (Gill *et al.* 1991) on bushfires and their effects, very little effort has been devoted to characterizing and quantifying the attack that the burning of various types of vegetation might generate in the vicinity of buildings. The literature was recently reviewed (Rudolph 1993a) and a qualitative approach developed for assessing the effects of individual species. Fourteen attributes were identified and each was considered separately for its effect on each of the four elements of bushfire attack (embers, radiation, flame and wind) (see Table 1). The Table shows, for example, that when considering the attributes of bark texture, increasing looseness (as opposed to tightness) tends towards an increase in ember attack. Although there are a large number of 'unknowns' in the Table, this work provides useful information for assessing bushfire attack and a systematic basis for accumulation of data for the future.

Much more data is required before a quantitative approach can be taken and viable models for bushfire attack developed. In the meantime, we must rely on experience and expert judgment to determine the likely modes and magnitude of attack that a given vegetation loading will produce.

TABLE 1.

Effects of attributes of plants on four modes of bushfire attack.

Effect of attributes on mode of attack
I = increase, D = decrease,
NE = negligible or no effect, ? = unknown

ATTRIBUTE OF PLANT SPECIES		DEGREE OF ATTRIBUTES	EMBERS	RADIATION	FLAME	WIND
1.	Moisture content of leaves	high/low	?	D/I	D/I	NE
2.	Volatile oil content of leaves	high/low	?	I/D	I/D	NE
3.	Mineral content of leaves	high/low	?	D/I	D/I	NE
4.	Leaf fineness	broad/narrow	?	?	D/I	?
5.	Density of foliage	closely spaced/sparse	?	?	?	D/I
6.	Continuity of plant form	connected/broken	?	?	?	D/I
7.	Height of lowest foliage	high/low	?	?	D/I	I/D
8.	Size of plant – volume	large/small	I/D	I/D	I/D	?
	– spread	wide/narrow	?	?	?	D/I
9.	Dead material on plant	heavy/light	I/D	I/D	I/D	NE
10.	Bark texture	loose/tight	I/D	?	?	NE
11.	Quantity of ground fuel	heavy/light	I/D	I/D	I/D	NE
12.	Particle size of ground fuel	fine/coarse	?	?	I/D	NE
13.	Compactability of ground fuel	packed closely/ loosely	?	D/I	D/I	NE
14.	Mineral content of ground fuel	high/low	?	D/I	D/I	NE

Attack Modification Module

The actual attack experienced by a building will be determined by both the environmental conditions and the landscape. Although the environmental conditions affecting bushfires (windspeed, temperature and humidity) are well known and are incorporated into various fire spread models, their effects on the bushfire attack (burning debris, radiation, flames and wind) on a building are not well defined and there are no models to predict this attack. The attack is also affected by features of the landscape (slope, windbreaks, radiation barriers, cleared areas, etc.) but again no models are available.

The overall attack on a building can be beneficially modified by managing the vegetation, mitigating local winds and changing landscape features. All these measures constitute the 'landscape approach'. More explicitly, this approach involves the selection and location of vegetation, the manipulation of the landform, the siting and design of amenities such as walls, fences, paths, driveways, paved areas, cleared open spaces and the siting of the buildings themselves. A considerable amount of qualitative information and advice on implementing such measures is available and this has been brought together in a recent handbook 'Building in Bushfire-prone Areas – Information and Advice' (Ramsay and Dawkins 1993).

A scheme for assessing the performance of individual plants in terms of their 'flammability', 'ability to produce ground litter' and 'barrier forming ability' based upon their 'attributes' has been developed (Rudolph 1993b). This scheme is summarized in Table 2. To provide an overall assessment for a particular species, the scores could be simply added up, but the result would be distorted as there is, at present, no weighting system for either the attributes or the degree of importance of the three performance characteristics. It should be possible to arrive at an overall assessment using a rules-of-combination method as described by Hopkins (1977). In this method, rules would be developed that state levels at which individual attributes and combinations of them, become critical. In the meantime, certain critical attributes can be red-flagged for special attention. The scheme provides a basis for decisions to be made with regard to managing vegetation.

As indicated above, we can generally only go so far in mitigating the bushfire attack on a building using the landscape approach. In addition, a lack of maintenance of some landscape measures used, especially with regard to vegetation management, can limit the long-term viability of this approach (compared with the building approach).

Building Response Module

In the last ten years much has been learnt concerning the behaviour of building materials subjected to bushfire attack and the influence that design has on the

TABLE 2

Effect of attributes of plants on their performance characteristics.

Effect of attributes on mode of attack
I = increase, D = decrease,
NE = negligible or no effect, ? = unknown
– = effect considered elsewhere in table

	ATTRIBUTE OF PLANT SPECIES	DEGREE OF ATTRIBUTES	FLAMMABILITY	PROVISION OF GROUND FUEL	BARRIER FORMING ABILITY
1.	Moisture content of leaves	high/low	D/I	–	NE
2.	Volatile oil content of leaves	high/low	I/D	–	NE
3.	Mineral content of leaves	high/low	D/I	–	NE
4.	Leaf fineness	broad/narrow	D/I	–	I/D
5.	Density of foliage	closely spaced/sparse	I/D	–	I/D
6.	Continuity of plant form	connected/broken	I/D	–	I/D
7.	Height of lowest foliage	high/low	D/I	–	D/I
8.	Size of plant – volume	large/small	I/D	–	–
	– spread	wide/narrow	–	–	I/D
9	Dead material on plant	heavy/light	I/D	–	NE
10.	Bark texture	loose/tight	I/D	–	NE
11.	Quantity of ground fuel	heavy/light	I/D	I/D	NE
12.	Particle size of ground fuel	fine/coarse	I/D	I/D	NE
13.	Compactability of ground fuel	packed closely/ loosely	D/I	D/I	NE
14.	Mineral content of ground fuel	high/low	D/I	D/I	NE

ignition and destruction of buildings. Nearly all the information has been gathered by surveying the fate of buildings in actual bushfires and statistical analysis of the attributes of the landscape and buildings (Cole 1983; Ramsay *et al.* 1986; and Wilson and Ferguson 1986). Such analyses can be used as a model for predicting building survival given certain vegetation attributes and building features, but the one model that has been published (Wilson and Ferguson 1986) is limited in terms of the number of parameters included. Such models are generally specific to the area surveyed rather than of general applicability, and should only be used within the limitations imposed by the original database.

Surveys of buildings involved in bushfires that have been carried out (McArthur and Ramsay, unpublished) since those of the 1983 Ash Wednesday fires (Ramsay *et al.* 1986; Wilson and Ferguson 1986) have tended to support the conclusions of previous surveys. Table 3 summarizes the fate of the houses and indicates the significant role that people played in preventing the destruction of a majority of those houses that survived.

Some experimental work has been carried out to understand the parameters that affect the ignition of timber by burning debris under bushfire conditions (McArthur and Lutton 1991). A laboratory study of the ignition of building details incorporating timber under bushfire conditions, was carried out using 'mock-ups' of the these details using both realistic (leaves and twigs) and artificial miniature timber crib ignition sources. Parameters such as mock-up type, moisture content of the timber comprising the mock-up, temperature and relative humidity of the experimental atmosphere were examined. It was found that all these parameters affected the ignition and flame propagation induced and that under conditions typical of a severe bushfire (40°C, 10 per cent relative humidity, 5 per cent timber moisture content), only very small amounts of fuel were required to cause ignition. These results support the belief, based on field studies, that ignition of exterior building details made of timber plays an important role in the destruction of buildings in bushfires.

A study of the behaviour of aluminium building products in bushfires has been carried out to assess the validity of assertions that they perform poorly under bushfire conditions (McArthur 1991). The work was conducted in two parts: an examination of data from bushfire damage surveys and laboratory experiments in which window assemblies were exposed to radiant heat from a furnace. Data from surveys were augmented with information from a specific questionnaire. Analysis of this data did not provide any support for the belief that houses incorporating aluminium building products are at greater risk of being destroyed. The laboratory experiments on both timber- and aluminium-framed windows showed their performance under simulated bushfire conditions to be similar in that the glazing cracked before the frames became involved.

TABLE 3

Agency carrying out fire fighting activities and fate of houses.
(S = surviving house and D = destroyed house)

	AVOCA AND MELTON VICTORIA		TOCUMWAL NSW		NSW CENTRAL COAST		STRATHBOGIE	
	JANUARY 1985		JANUARY 1990		DECEMBER 1990 AND OCTOBER 1991		DECEMBER 1990	
AGENCY	S	D	S	D	S	D	S	D
Occupants	41	3	16	0	8	0	13	2
Fire brigade	5	5	2	0	6	0	0	0
Occupants and fire brigade	5	0	0	0	2	0	5	0
Others	7	0	0	0	2	0	0	0
None	10	28	1	0	0	5	3	1
Unknown	17	29	9	3	7	7	8	0
Subtotal	85	65	28	3	25	12	29	3
Total	150		31		37		32	

Both the surveys and the laboratory work provide a basis for assessing the response of a building to a given bushfire attack and designing against it using the 'building approach'. The current state-of-the-art with regard to information and advice on measures that might be employed for individual building elements in the building approach has been compiled in a recent handbook (Ramsay and Dawkins 1993). This handbook reproduces the requirements of the Australian Standard which sets out minimum measures for protection against burning debris (Standards Australia 1991), and discusses additional measures which may be used for further protection against burning debris, and measures for protection against attack by radiant heat, flame contact and wind. It is intended that designers will select measures for each building element, tailored to the type of bushfire attack envisaged. However, no quantitative measures are given and expert judgement is required to select appropriate measures.

FUTURE RESEARCH

One can identify the modules of an integrated approach to designing for building survival in bushfires in a qualitative fashion and, with expert opinion, use such an approach to produce a range of design solutions that will undoubtedly improve building survival. However, much more data is required before a quantitative approach can be used. Such an approach is needed if one is to develop appropriate mathematical models of the interface of urban areas with the countryside. This quantitative approach will enable:

(a) trade-offs between landscape and building design approaches;

(b) cost-effective design solutions to be identified; and

(c) actual prediction of building survival.

In particular, data are required on the bushfire attack potential for various plants, how that attack is modified by various landscape components and design measures, and the likelihood that a given attack will cause ignition and destruction of buildings of particular combinations of materials and designs.

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